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TECHNOLOGICAL DEVELOPMENT OF THE RUSSIAN CITIES IN A HUNDRED-YEAR RETROSPECTIVE

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The article analyzes the technological evolution of multi-apartment housing construction in 18 Russian cities from 1917 to 2023. The authors introduce an original methodology for analyzing technological modes (K3, K4, K5), drawing on Russia's largest housing dataset— the House Register— which contains detailed information on tens of thousands of buildings. The methodological framework is based on a combination of Kondratiev's long wave theory, evolutionary economic geography, and the structural analysis of urban real estate. Three waves of technological development are identified: the wooden-brick mode (K3), mass panel housing construction (K4), and monolithic construction (K5). A typology of cities is developed according to the nature of their transition between modes— from technological leaders to laggards remaining trapped in previous cycles. Special attention is given to the role of brick housing as an inter-mode connecting element, and to the diverse trajectories of transition to monolithic construction, including changes in foundation technologies. A detailed year-by-year analysis makes it possible to identify the characteristic phases of technological cycles: introduction, expansion, maturity, and decline. The article proposes criteria for diagnosing the renaissance of older technologies (e.g., the renewed growth of panel housing in the 2000s) and for distinguishing inertia from genuine technological

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shifts. The findings have practical significance for urban development policy, particularly amid the growing need to transition toward energy-efficient and adaptable urban forms.

Technological mode, multi-apartment housing construction, long Kondratiev waves, panel construction, monolithic housing construction, brick construction, evolutionary urbanism, urban technological dynamics.

Introduction

The relevance of the research is substantiated with several circumstances. First, it is a long-term retrospective study of the technological development of not one, but almost twenty of Russia's largest cities located in various geographical zones and federal districts. As a rule, the relevant data were collected by teams of historians who worked for a long time in state and departmental archives to obtain decades-long series of indicators from annual reports of structural enterprises. These data then became the basis of their works on the economic history of the city.

To follow this path, even for twenty cities, it would take years of work and teams of specialists. We chose a more efficient approach by focusing exclusively on technological development—specifically, on technologies of multi-apartment housing construction. This narrowed the research perspective, but it provided an unparalleled range of sample for a long-term retrospective analysis – almost twenty Russian cities were simultaneously covered by the study.

Second, the research focuses on factors that contribute to or hinder long-term technological evolution, using the example of not a single industrial enterprise or industrial sector, where they are more obvious and transparent, but large and medium-sized cities as a complex social phenomenon within which technological evolution is intricately intertwined with natural conditions and the social environment. This emerging field of techno-social urban evolution is still in its early stages, yet it already offers promising prospects for future researchers and practitioners.

Third, our research provides new knowledge for management decision makers in the cities under study in terms of understanding the current phase of the city's innovative development in the context of the long-term technological dynamics identified in this paper.

The subject of the research is the long-term technological development of Russian cities on the example of housing construction (technologies). The object of analysis is a sample of 18 large and medium-sized Russian cities. It was decided to use the population of 250 thousand people as the lower threshold of the sample, because this number is identified in the Russian Spatial Development Strategy adopted in December 2024 as characterizing the "core of an urban agglomeration"[1]. Moscow and Saint Petersburg, as constituent entities of the Russian Federation and therefore different in status from all other Russian cities, were decided not to be included in the study (they require a special approach and separate research).

The aim of the study is to identify the patterns and features of the technological dynamics of 18 Russian cities in a hundred-year retrospective. The aim identified the solution of three tasks: 1) to characterize the essential patterns and features of the technological development of Russian cities in 1920s–1950s (K3 – the third Kondratiev[2]);

[1] Cities with a population of 250 thousand people have assumed the status of agglomerations. Available at: https://tass.ru/ekonomika/15091945

[2] The third Kondratiev (K3) is understood in this article as a period of mass construction of wooden and brick multi-apartment housing (MAH) using early industrial technologies, which took place in Russian cities from the beginning of the 20th century (when multi-apartment housing itself only appeared) to the end of the 1950s. However, due to the inaccuracy of pre-revolutionary data on the annual delivery of multi-apartment housing, we can only consider it since the 1920s. The fourth Kondratiev (K4) is understood in this paper as the era of panel housing construction, which is a period of mass construction of panel housing using reinforced concrete floors and panels, which took place in Russian cities from the 1960s to the beginning / first two decades of the 21st century. The fifth Kondratiev (K5) is understood in this paper as the era of monolithic housing construction, which relies on new technologies for pouring concrete mixture into formwork directly on the construction site and has been largely applied in Russian cities since the second decade of the 21st century.

1960s–2000s (K4); 2010s+ (K5); 2) to classify Russian cities according to dynamics of their transition from K4 to K5; 3) to carry out comparisons of similar cities to identify the factors influencing the speed of technological evolution.

The novelty of the research is determined by the analysis of cities through the lens of long-term technological dynamics. Though in recent years we have completed a series of six papers united by a common intention to explore the hundred-year technological dynamics at the level of a particular region (Magadan Region), the Arctic zone, the Northern Sea Route, and a particular enterprise (Arkhangelsk Seaweed Plant) (Pilyasov, Tsukerman, 2022a; Pilyasov, Tsukerman, 2022b; Pilyasov, 2023; Pilyasov, Kotov, 2024; Pilyasov, 2024; Pilyasov et al., 2025), the factual basis for investigation into the technological evolution of cities was unclear for a long time. What criteria should we use to determine the exact phase of the fourth or fifth Kondratiev for a particular city? It was necessary to create a special research methodology, customized to the analysis of the long-term technological dynamics of cities.

Methodology and methods, research data

The traditional approach to the analysis of technological development of cities is being globally elaborated today within the framework of three main directions. The first direction relates to the "smart city" concept, which emphasizes new economic specializations in AI technologies, the creative capacities of local talent, new models of urban spatial organization, and innovations in housing and utilities. Dozens of monographs and hundreds of articles have been published on this topic both in Russia and internationally (Ahad et al., 2020; Albino et al., 2015; Caragliu et al., 2011; Hassankhani et al., 2021; Mora et al., 2021; Nikki, Kim, 2021; Srivastava, Sharifi, 2022; Balakhonova, 2023; Afanasyeva, Popova, 2022, etc.).

The second direction is based on ratings of innovative urban development which are very popular both in Russia and internationally and, despite their clearly applied nature, have already become the subject of scientific research both in terms of analytical design and as a tool for comparisons between similar cities (for example, global, capital, million-plus cities, etc.). For example, in Russia such tools include the Higher School of Economics' rating and the Ministry of Construction's annual IQ Index of digital transformation[3].

The third direction includes a few works devoted to the emergence of a new technological order in cities and its impact on the evolution of urban planning, urban environment, management practices and priorities of economic development[4] (Gavayler, 2018; Mazaev, 2018).

None of these directions could allow us to create a methodological platform for our research. Therefore, it was decided to create our own theoretical framework, specifically for this study, consisting of three components. The first element includes the Kondratiev – Perez – Glazyev long wave theory, which is fruitfully developed for the country level (Kondratiev, 1993; Glazyev, 1993; Perez, 2002; Perez, 2010; Lema, Perez, 2024), which we have already adjusted to the level of particular enterprises, regions and the Arctic zone of the Russian Federation in previous works. And, of course, it can be useful for urban level studies as it helps to understand the logic of long-term ("structural") technological evolution.

The second component includes works by economists, historians, and economic geographers within the evolutionary paradigm: evolutionary economics, evolutionary

[3] Based on 47 indicators, this index evaluates the level of implementation of intelligent systems and digital technologies in various areas of urban governance.

[4] Lipetskaya M.S. (Ed.). (2017). Tekhnologii dlya umnykh gorodov [Technologies for Smart Cities]. Saint Petersburg: CSR – North-West; Gavailer A.V. (2018). Razrabotka strategii razvitiya goroda v usloviyakh smeny tekhnologicheskikh ukladov: avtoref. dis. … kand. ekon. nauk [Creation of a Strategy for City Development in the Context of Changing Technological Patterns: Candidate of Sciences (Economics) Dissertation Abstract]. Moscow: MSU.

economic geography, and social evolution (Nelson, Winter, 1982; Schumpeter, 1982; Korotaev et al., 2009; Boschma, Martin, 2010).

These works, with all their variety of subjects, help to see in a hundred-year retrospective not just urban history or development, but a reflection of the basic laws of evolution, as they are known and studied by experts in evolutionary biology and social evolution.

The third component (oriented toward the practical implementation of the study) was the most important and completely original. It was necessary to see housing construction not as it is traditionally understood (social phenomenon of meeting basic human needs), but as a technological phenomenon associated with certain materials, means of production and construction technologies inherent in each historical era. The city's physical form is shaped by its real estate, with residential buildings – present in every city – forming its core (in most of the cities under consideration, it makes up from 50 to 70% or more of the total assets of urban real estate), which therefore can serve as a basis for comparing cities with very different economic profiles. Thus, the central assumption of our research is that the overall technological level of a city can be inferred from long-term changes in its dominant technologies of multi-apartment housing construction. Despite the vulnerability of this situation – due to the underestimation of city-specific innovations inherent in each technological era, for example, in digitalization and digital management, in assembly-line production, etc. – this was the only way to see the technological development of a city in a long-term hundred-year retrospective.

The main source of information on residential real estate in cities has become the House Register database, which is supported by the Territorial Development Fund. It is the most detailed and temporally extensive database on multi-apartment buildings in the Russian Federation[5], which contains several dozen indicators. Ten of them were selected for our analysis *(Tab. 1)*.

The key indicators are the year of construction (*built_year*) and the year the building entered operation (*exploitation_start_year*). The applied construction technologies and materials are compared with them. Thus, as a result of the analysis per year, technological waves ("panel", "brick", "monolithic") and

Table 1. Structure of the used House Register database of the information system "Housing and utilities sector reform"

Name of the database field	Description of the database field
id	ID of the house in the database
region_id	RF constituent entity (FIAS code – federal information address system)
city_id	City (FIAS code)
built_year	Year built
exploitation_start_year	Year of exploitation start
house_type	Type of the house (MAH/special housing, etc.)
area_total	Total area of the house, sq. m.
foundation_type	Foundation type (girder, piled, spread, combined, prefabricated, post)
floor_type	Floor type (wood, reinforced concrete)
wall_material	Supporting wall material (brick, wood, panel, monolithic, block, reinforced concrete, mixed)
Compiled based on: https://xn--80adsazqn.xn--p1aee.xn--p1ai/opendata (accessed: February 05, 2025).	

[5] Due to the narrow time range of the data available (from ten to fifteen years) and their aggregated condition, it was impossible to use other databases: Rosstat – federal statistical monitoring form No 1 – housing stock "Information on housing stock"; Ministry of Construction of the Russian Federation – EMISS (Total living floor space in multi-apartment buildings), indicator 57479; Public information system of housing and utilities sector (Dom. RF).

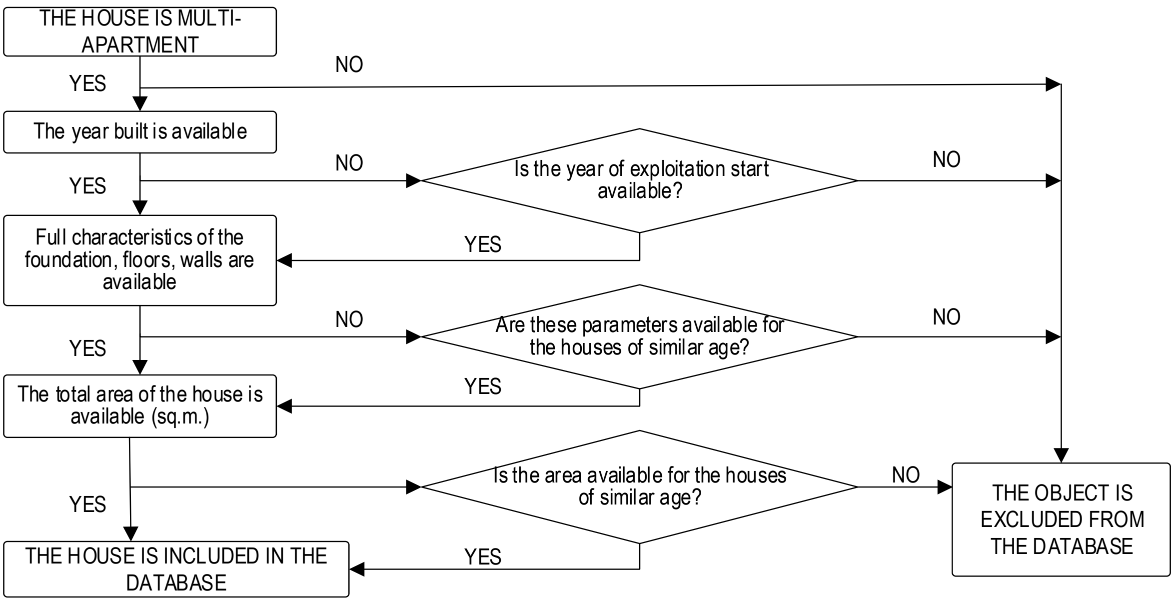


Figure 1. The algorithm for creating a database of multi-apartment buildings

Source: own compilation.

periods of change of technological paradigms in urban housing construction are revealed *(Fig. 1)*.

Though the data on annual construction of multi-apartment buildings in many cities reach the 19th century, eventually we decided to limit the study to the post-revolutionary period due to the significant gaps in data, the overloaded 1917, which included hundreds of houses obviously built earlier. Special-purpose and terraced housing types were excluded from the database.

If all the necessary parameters were available, such as the year built, full characteristics of the materials of wall, floors and foundations, as well as the area of the house, the building was included directly in the database. In case of incomplete information, expert calculation methods were used.

When the year of construction was missing, the year of commissioning was used as a proxy, which in the vast majority of cases coincided with the notified year of construction. This allowed the inclusion of an additional 3–5% of buildings in the analysis.

For multi-apartment buildings where construction materials were not specified, the characteristics of similar neighboring/comparable buildings were used to fill in the gaps. This allowed the inclusion of an additional 3–5% of buildings in the analysis. These measures ensured the representativeness of the sample *(Tab. 2)*, which on average reached at least 75% of the total number of multi-apartment buildings located in selected cities.

The main emphasis in the most laborious preliminary analysis was placed on data visualization in the form of graphs on the dynamics of the delivery of the total area of wooden, brick, panel, block, monolithic multi-apartment buildings and their share in the total housing delivery; dynamics of the average size of the delivery of wooden, brick, panel, block, monolithic multi-apartment buildings; dynamics of the share of buildings with reinforced concrete floors, expressed as a percentage of the total constructed area; dynamics of the structure of the total area of multi-apartment buildings by type of walls in absolute terms; dynamics of the delivery structure of the total area of apartment buildings by type of walls, in %; dynamics of the input structure of the total area of multi-apartment buildings by type of foundation in absolute terms; dynamics of the delivery structure of the total area of multi-apartment

Table 2. A sample of cities included in the study

City	Population as of 01.01.2024, people	Analyzed years	Number of cells (houses) with a full description: year built, total area, type of walls, type of foundation, type of floors
More than 1 million people			
Novosibirsk	1633851	1917–2021	7135
Yekaterinburg	1536183	1917–2022	7435
Krasnoyarsk	1205473	1917–2020	5201
Nizhny Novgorod	1204985	1918–2021	6310
Chelyabinsk	1177058	1928–2023	5522
Samara	1158952	1918–2018	6807
Rostov-on-Don	1140487	1918–2023	4828
Krasnodar	1138654	1917–2019	2045
Omsk	1104485	1924–2022	6439
Voronezh	1046425	1928–2022	4594
Perm	1026908	1918–2019	4779
Volgograd	1018898	1929–2021	4830
A sample of 12 out of 16 Russian cities of this size – 75%			
500 thousand – 1 million people			
Tyumen	861098	1917–2021	3370
Khabarovsk	615570	1925–2021	3376
Irkutsk	606369	1918–2021	3779
Vladivostok	591628	1919–2019	3151
A sample of 4 out of 20 Russian cities of this size – 20%			
250–500 thousand people			
Arkhangelsk	296665	1918–2021	3703
Murmansk	266681	1929–2016	2014
A sample of 2 out of 42 Russian cities of this size – 4.8%			
Compiled based on: House Register database.			

buildings by type of foundation, in %. Totally, 15x18 = 270 dynamics graphs were built.

Main results

An analysis of the evolution of technological paradigms in the housing construction of Russian cities allows us to identify three waves: the third Kondratiev based on technologies of wooden and brick construction of multi-apartment buildings, which developed in the 1920s–1950s; the fourth Kondratiev cycle, characterized by mass panel housing technologies, developed in the 1960s–2000s; the fifth Kondratiev cycle, driven by monolithic construction technologies (alongside the unprecedented rise of low-rise, individual housing compared with earlier periods, i.e. a decrease in the importance of the construction of multi-apartment buildings), which began in 2010s+ in Russian cities. The fourth Kondratiev cycle shows the clearest and most coherent internal phase structure.

Brief description of the features of the K3 cycle (1920s–1950s) in the development of Russian cities

It is impossible to talk about the full disclosure of all phases of the third Kondratiev in urban housing construction, wooden and brick, due to the fact that the phenomenon of multi-apartment housing, based on industrial mass, rather than individual, artisanal technologies, arose in Russian cities only in the pre-revolutionary period. Prior to this, pre-industrial methods of building small houses made of stone, wood, brick, on girder and stone foundations, with wooden floors were used.

Until the end of the 1950s, the absolute volume of construction of wooden multi-apartment buildings in cities with strong traditions of wooden housing construction (for example, in Arkhangelsk) increased, although the share of wooden housing in the total area of apartment buildings decreased here already from the mid-1950s due to the massive delivery of brick and block apartment buildings. Throughout the third Kondratiev cycle – nd even earlier, during the 19th century – a competition between wooden and brick construction persisted in cities. It manifested itself in the first decades of the 20th century and in the construction of multi-apartment buildings.

However, there is a fundamental difference between these wall materials. If the brick survived both the third and fourth (panel) and entered the fifth (monolithic) Kondratiev, wood as a structural material rapidly lost ground with the onset of the fourth Kondratiev cycle in the 1960s. Thus, wood—highly sensitive to shifts in technological paradigms—should be regarded as the key marker of this period, and not the "inter-paradigm" brick, that should be considered as a marker of this period (further, at the turn of the century, wood will reappear, but in individual, rather than multi-apartment residential construction).

Absolutely in the spirit of the postulates of evolutionary biology, after the total disappearance of wood as a mass material for the construction of apartment buildings, in some cities with long-standing traditions of wooden house construction, its temporary return was observed in the 1960s and even in the 1970s as a wall material and/or the material of the floors of multi-apartment buildings.

The leading cities, which preserve the traditions of wooden housing construction, are determined by the maximum percentage of the total area of wooden multi-apartment buildings built during the observation period in the 20th century in the total area of all multi-apartment buildings built. These are Arkhangelsk (the share of the area of wooden multi-apartment buildings is 20%), Irkutsk (3%), Khabarovsk (1.5%), Nizhny Novgorod and Samara (about 1%). In the rest of the cities in our sample, the proportion of wooden multi-apartment buildings is significantly lower.

The era of panel housing (K4, 1960–2000+)

The arrival of panel housing, which is associated with the fourth Kondratiev cycle, is diagnosed on most dynamics graphs *(Fig. 2a, b)* by an almost vertical line – the delivery from zero to maximum values over the entire half-century period was carried out in a matter of years in almost all the cities under consideration, although there were significant differences in the details of this cycle in Russian cities. Reinforced concrete panels are becoming the basis of mass low-cost residential construction of multi-apartment buildings, which are rapidly replacing other building materials and have become the main method of housing construction for several decades in many of the cities under consideration.

From the point of view of the Kondratiev cycle, the panel cycle can be called "canonical": in many cities it lasts about half a century, after which it begins to decline, it is clearly divided into four phases – development (the first 8–10 years), consolidation (the next 10–12 years), the golden age (about 15 years) and the crisis (with a possible renaissance) – about 15 years, which fell at the end of the 1990s and the beginning of the 2000s.

The half-century cycle of panel housing construction is represented by two main types of dynamics: with either a single dominant peak (Fig. 2a) or several comparable peaks spanning the Soviet and post-Soviet periods (Fig. 2b).

Despite the "friendly" mass start of the panel cycle at almost the same time in all the cities of our sample, there were significant differences between them in the course of K4, which can be reduced to several points. First, the moment of the appearance of the first panel house differed significantly, as a rule it was much earlier than the start of the panel cycle itself: by more than 30 years in Rostov-on-Don, where the forerunner of the future mass panel building appeared in 1928, in Irkutsk – in 1931; in most cities this preceded the mass rollout of panel housing by 10–12 years; in Arkhangelsk and Tyumen, it almost coincided with the beginning of K4 *(Tab. 3)*.

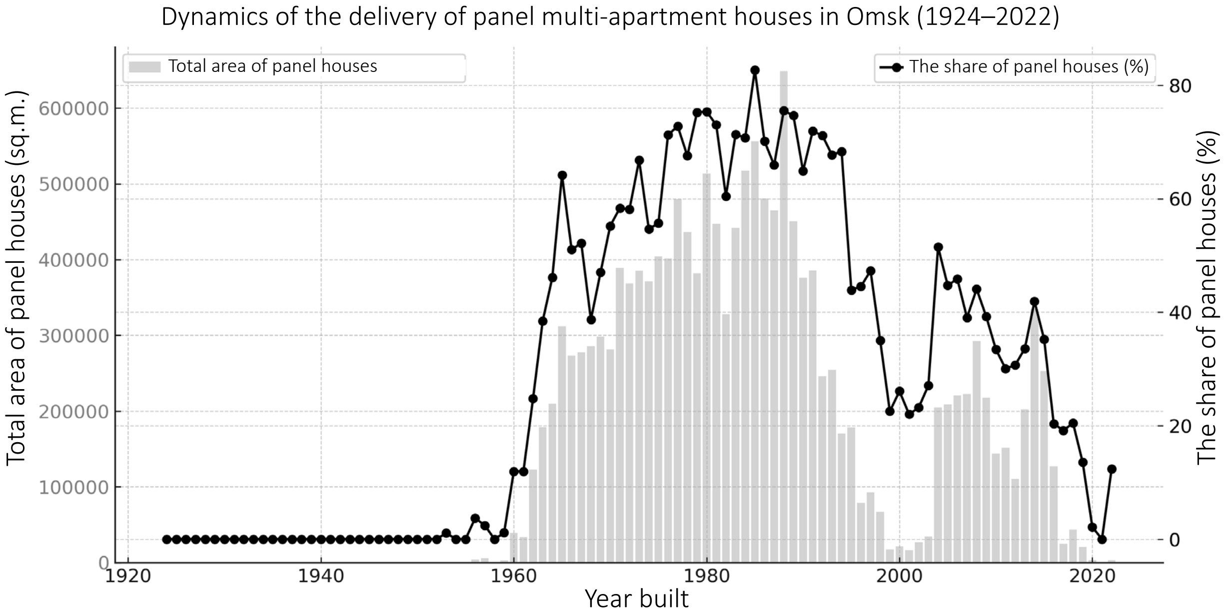


Figure 2a. Peaky type of dynamics of the K4 panel cycle

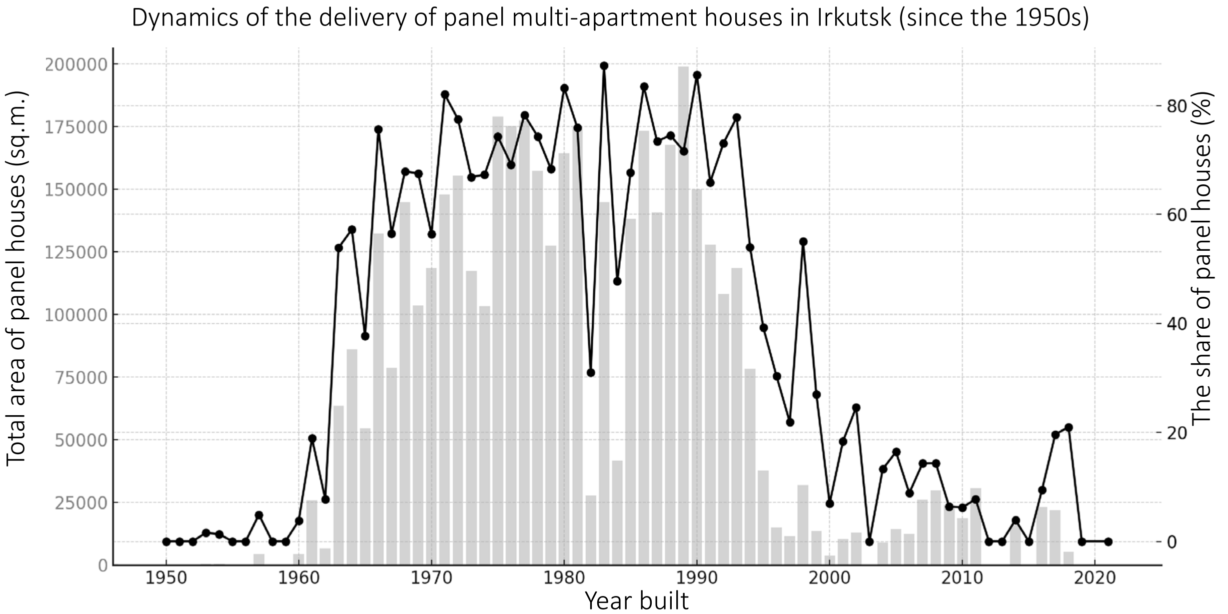


Figure 2b. Multipeak type of dynamics of the K4 panel cycle

Source: own compilation.

Second, the timing of "saturation" – when panel housing reached 50% of all new construction – varied substantially among cities, when the share of panel houses began to account for half of the total area of all multi-apartment buildings delivered: in half of the cases, it was reached already in the first decade of the start of the cycle, but in Voronezh only in 1982, in Krasnodar in 1978, and in Volgograd in 1977 (traditionally brick-oriented cities of the Black Earth region and the Russian South lagged behind in adopting panel construction).

Third, as already noted, the type of multi-decade dynamics of the panel cycle differed: from the classic single peak, after which there was a prolonged decline, to the presence of several (two or more) equivalent peaks in the Soviet and Russian time. Fourth, in some cities there were vivid cases of the renaissance of panel housing construction – as a rule, already

Table 3. Differences in the development of the panel cycle between cities

City	The share of panel MAH in the total area of MAH as a whole, %	The type of dynamics by the number of peaks	The appearance of the first panel house, year	Delivery of panel houses of 25% of the total area of all houses delivered, year	Delivery of panel houses of 50% of the total area of all houses delivered, year	The average share of panel houses delivered by area in the total MAH delivered in the last five years, %	The type of dynamics
First group							
Murmansk	69	O	1952	1963	1965	more than 75	-
Chelyabinsk	62	M	1936	1962	1964	100	++
Krasnoyarsk	57	M	1948	1948	1963	19	++
Omsk	54	O	1953	1963	1965	10	+
Vladivostok	52	O	1937	1962	1967	less than 1	+
Second group							
Arkhangelsk	45	M	1961	1967	1970	19	-
Novosibirsk	45	M	1954	1962	1964	16	++
Perm	42	M	1950	1964	1971	22	+
Khabarovsk	41	M	1949	1963	1973	3	+
Irkutsk	41	M	1931	1931	1963	17	-
Nizhny Novgorod	40	M	1950	1965	1969	22	-
Third group							
Rostov-on-Don	38	O	1928	1947	1947	30	-
Samara	36	O	1942	1961	1962	2	-
Tyumen	35	M	1961	1967	1976	60	+
Voronezh	34	M	1950	1972	1982	22	++
Yekaterinburg	34	M	1944	1961	1967	36	-
Volgograd	31	M	1958	1962	1977	less than 3	+
Krasnodar	19	M	1950	1962	1978	1	-

Note: O – one peak, M – multipeak structure; + renaissance in monolithic era; ++ prolonged panel cycle; - no renaissance of panel housing.
Source: own compilation.

in a new "monolithic" cycle – as a kind of retrogression[6] (just as wood returned to multi-apartment housing construction in the panel cycle in the 1960s and 1970s).

Fifth, the long-term "footprint" of the panel cycle varies significantly in the century-long perspective of the construction of multi-apartment buildings. The share of panel cycle houses accounts for more than half of the city's total housing stock in Murmansk, Chelyabinsk, Krasnoyarsk, Omsk, and Vladivostok. But it is significantly more modest (20–35%) and is often less than the proportion of brick apartment buildings in the cities of southern Russia: Krasnodar, Volgograd, Voronezh, Tyumen, Samara, Rostov-on-Don.

Moreover, reinforced-concrete floor systems displaced wooden floors with differing degrees of intensity across cities. Summarizing, we can state that there are two distinct patterns emerge: 1) rapid displacement of wooden floors at the outset *(Fig. 3a)*; 2) a decades-long consolidation of reinforced-concrete floors; *Fig. 3b*).

The cities differed in the time period between the appearance of the first house with reinforced concrete floors and the year when all the houses delivered had them. However, it should be clarified here that in the case of small

[6] Retrogression (from Latin retrogressio – backward movement) is a movement, development or change in the opposite direction, i.e. a return to an earlier, less developed or primitive state.

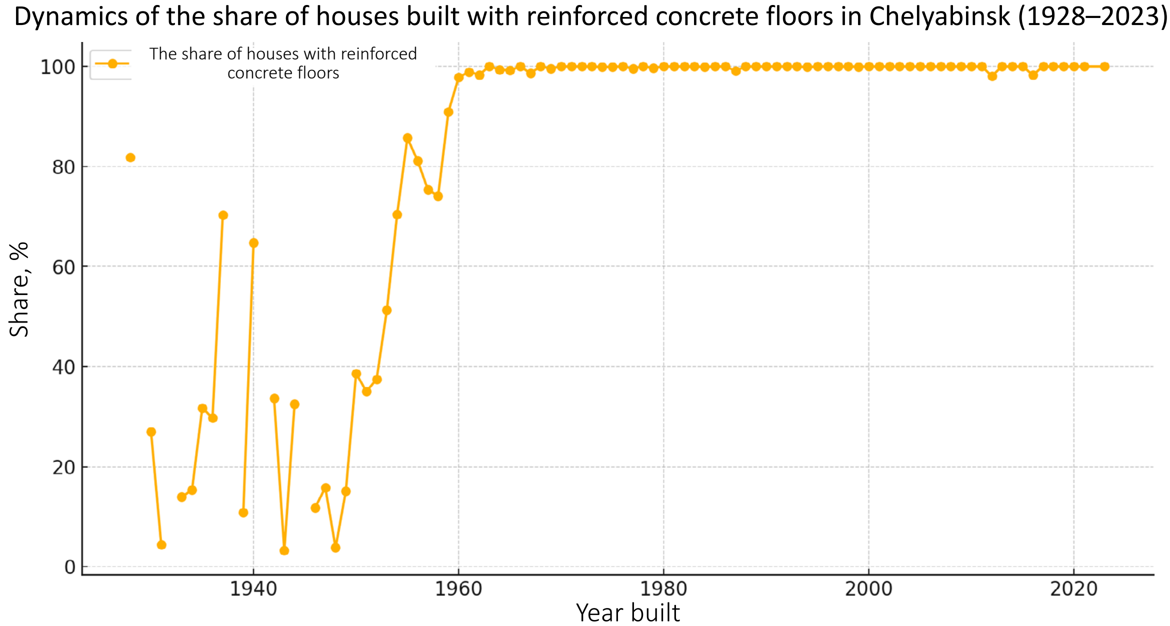


Figure 3a. Rapid displacement of wooden floors by reinforced concrete at the beginning of K4
Source: own compilation.

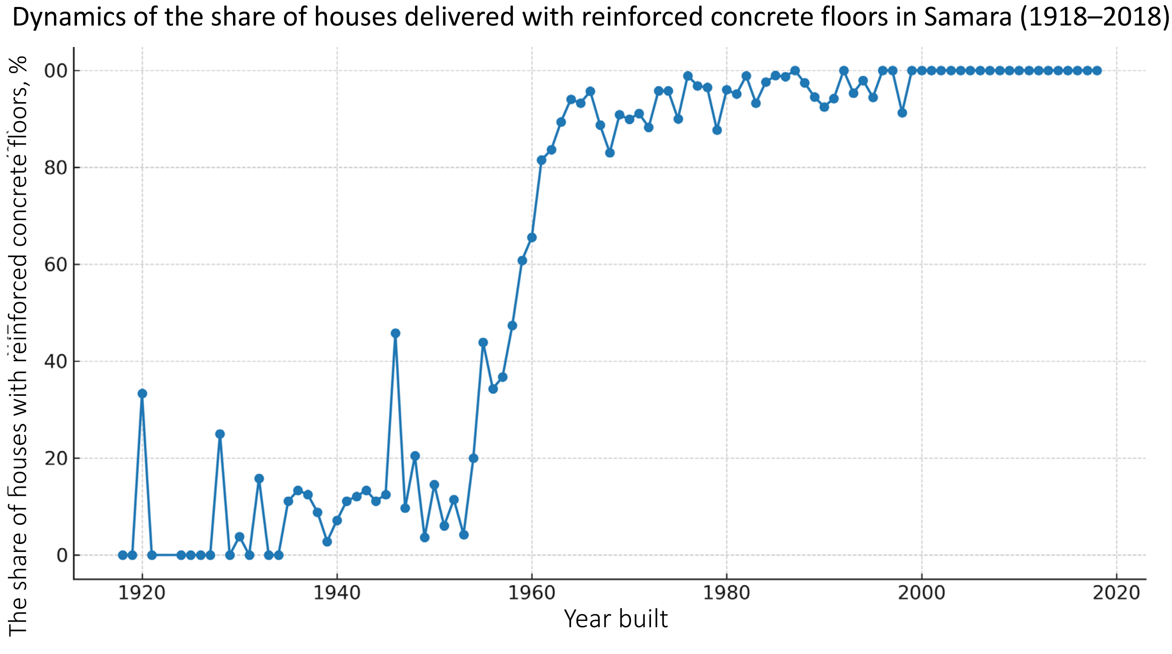


Figure 3b. Prolonged displacement of wooden floors by reinforced concrete at the end of K4
Source: own compilation.

delivery of new multi-apartment buildings, this one hundred percent could decrease again to 60–75% in subsequent years with more significant volumes of multi-apartment building delivery. In this case, reaching the "ceiling" was not stable. Therefore, the years of reaching the 100% level earlier than 1960 should be treated as "crafty", i.e. they do not indicate a genuine transition from wooden to reinforced concrete floors.

The minimum gap between the first appearance of a construction innovation and its total spread within the panel cycle is 25–30 years, but the majority of the sample cities have a gap of 40–45 years *(Tab. 4)*. The first appearance of an innovation characterizing the next technological cycle in multi-apartment housing construction occurs in the middle of the previous cycle, and for two thirds of the sample cities, the period of its mass implementation is almost half a century (this is the length of the longest wave).

Due to the simultaneous mass transition of all cities in the sample to the cycle of panel housing construction, there may be an illusion that the further development of industrial K4 took place absolutely identically in all cities of different sizes and locations. However, a detailed study of the course of this process shows that there were significant differences between cities in terms of the type of dynamics (one peak or many, the Soviet peak versus the Russian peak, etc.) and in terms of the role of the panel cycle as a whole in the century-old retrospect of multi-apartment housing (for example, southern cities clearly gave priority to brick housing, which dominated the total area of all delivered houses), and in terms of the speed of total approval of "panel" innovation, the length of the panel cycle (50 years or more, with a prolongation by "extra" decades). The transition to the lowest spatial level (from the country and region to the city) of the applied use of the technological paradigm of Kondratiev half-century cycles inevitably reveals greater variability than when it is used at the traditional country level.

The phenomenon of inter-paradigm (K3, K4, K5) enveloping brick housing construction in

Table 4. Differences between cities in terms of the gap between the first innovation and its massive rooting within the panel cycle, years

City	The year of the appearance of the first house with reinforced concrete floors	The year when the share of the area of houses with reinforced concrete floors was 25% of all delivered houses	The year when 100% of multi-apartment buildings were built with reinforced concrete floors
Krasnodar	1918	1918	1929?
Rostov-on-Don	1925	1928	1942?
Tyumen	1918	1918	1947?
25–30 years between 100% delivery of houses with reinforced concrete floors and the year of delivery of the first house			
Murmansk	1937	1938	1962
Chelyabinsk	1928	1930	1963
Volgograd	1932	1946	1965
40–45+ years			
Vladivostok	1919	1919	1960?
Irkutsk	1919	1919	1966?
Voronezh	1929	1929	1970
Novosibirsk	1929	1929	1970
Omsk	1928	1928	1971
Khabarovsk	1927	1927	1975
Perm	1928	1928	1975
Nizhny Novgorod	1927	1930	1975
Yekaterinburg	1935	1952	1978
60+ years			
Krasnoyarsk	1917	1917	1989
Samara	1878	1909	1992
Arkhangelsk	1940	1961	1999
Source: own compilation.			

the technological evolution of multi-apartment housing construction of the last century

Brick house construction can be called a "thing in itself" in the sense that it is not fully associated with any of the cycles we have considered (K3, K4, K5), but stretches between all of them – it is present in the wooden, panel, and monolithic cycle. In this sense, a brick can be likened to a trilobite[7], a long-lived Paleozoic fauna that outlived many other species. Brick housing construction goes through all the considered structures and performs an important connecting role. But at the same time, it also obeys a half-century cycle: for all the variety of situations in cities, the periods of maximum activity of brick housing construction, which are expressed in the peaks of its volumes, are half a century apart.

Brick house construction plays a substitute role in the transition period before the massive arrival of new, cheaper technologies and materials related to the new technological order. As soon as this new technology manifests itself in full force, brick housing construction

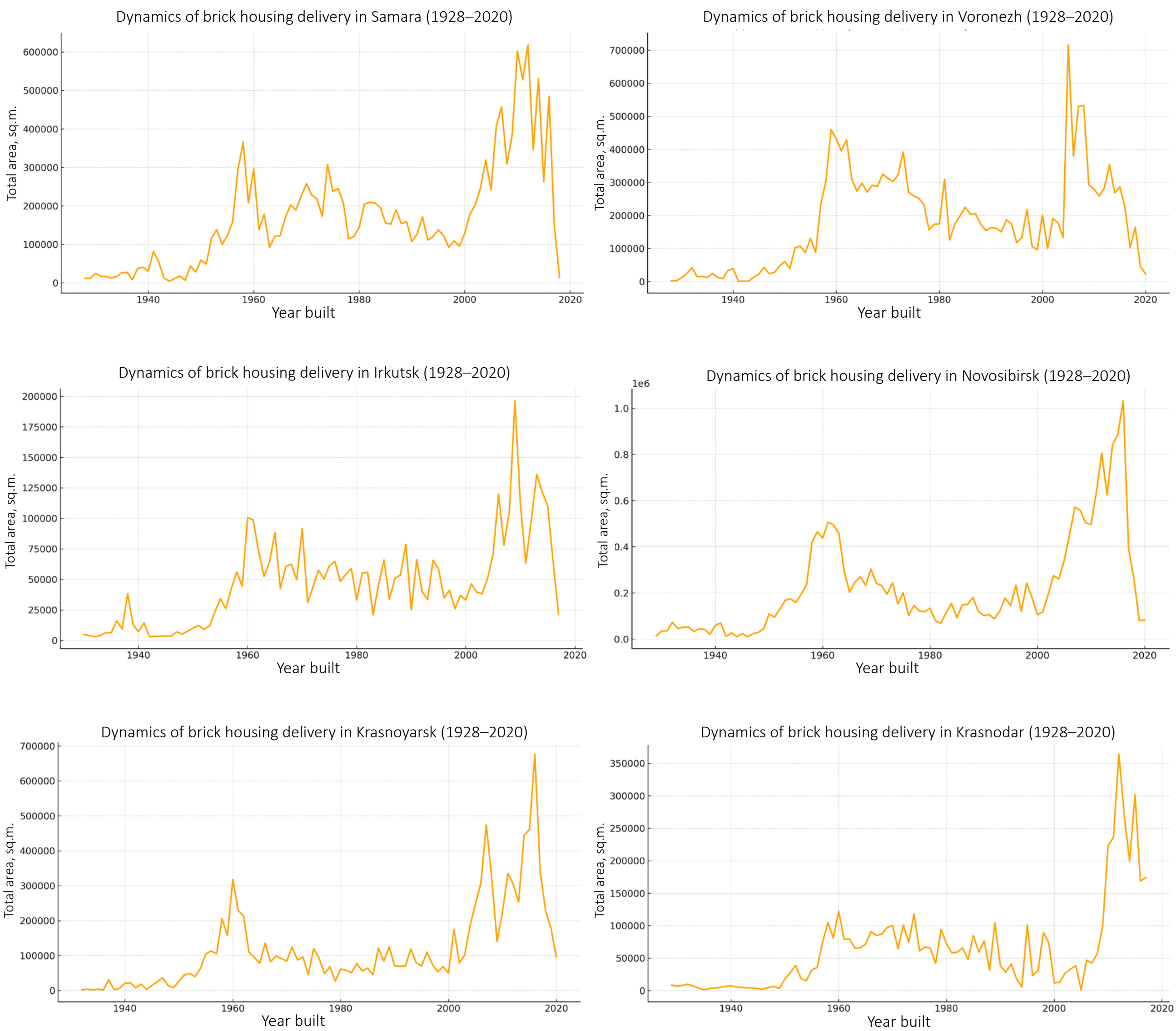


Figure 4a. The Russian peak of brick house construction exceeds the Soviet peak

Source: own compilation.

[7] Trilobites existed for about 270 million years, from the Cambrian to the Permian period, which is much longer than, for example, dinosaurs. During this time, trilobites have survived several mass extinctions, adapted to various conditions and evolved into a huge number of species.

immediately shrinks to modest volumes in order to come to the aid of urban housing construction again during a new crisis when the potential of the old paradigm is exhausted. Brick housing construction, as a crisis rescuer, *fills the inter-paradigm pause*, reaching peak growth rates and production volumes during this period. Therefore, the peak volumes of brick housing construction followed by a rapid decline are a sure indicator that there is a new cycle of urban housing construction.

A hundred-year retrospective of brick inter-paradigm housing construction across the entire sample of cities allows us to identify five types of dynamics dominated by two peaks separated by half a century in most types. The first type is characterized by an excess of the second Russian peak over the first Soviet one *(Fig. 4a)*.

At the same time, it should be remembered that the very nature of brick housing construction in the 1960s and 2000s changed significantly, which clearly reflects the change in the average size of a brick house during this period from hundreds to thousands of square meters[8], as a result of an increase in number of stories (in the 1950s and 1960s, five- and nine-story houses began to be massively built, previously there were two- and three-story houses, in the 1990s–2000s there were 10–12-story brick houses) and new technologies for the production of bricks (instead of the previous heavy bricks, the use of hollow and silicate bricks for the construction of light, durable walls).

The second type is characterized by the comparability of the values of the first Soviet peak and the second Russian one *(Fig. 4b)*, in the third type the Soviet peak exceeds the Russian one *(Fig. 4c)*, in the fourth type there is only one Soviet or Russian peak *(Fig. 4d)*.

The amazing plasticity of inter-paradigm brick housing construction, due to the ability of the brick itself as a building material with a thousand-year history to flexibly transform to

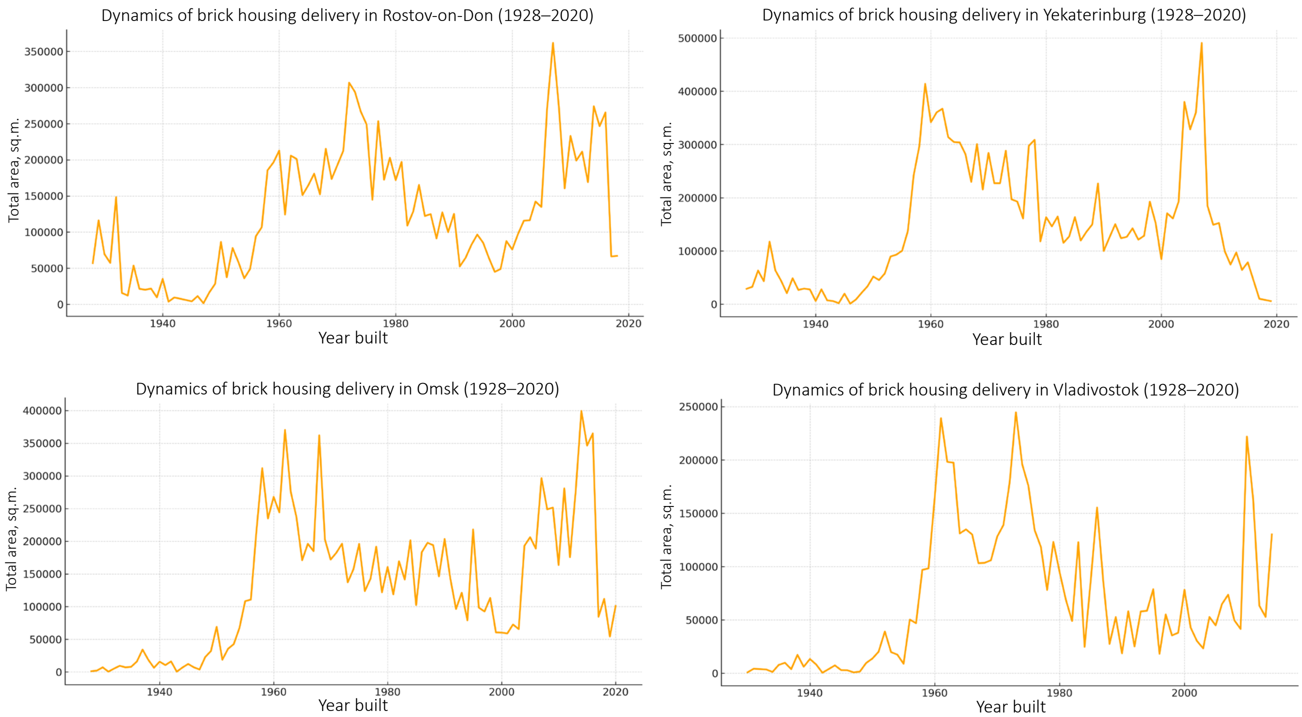


Figure 4b. The Russian and Soviet peaks of brick house construction are comparable

Source: own compilation.

[8] To be correct, it should be said that since the 2000s, the growth of the average size of brick houses has stopped or slowed down, because mass apartment-housing has become monolithic or panel, and bricks have been used in low-rise construction, in smaller buildings.

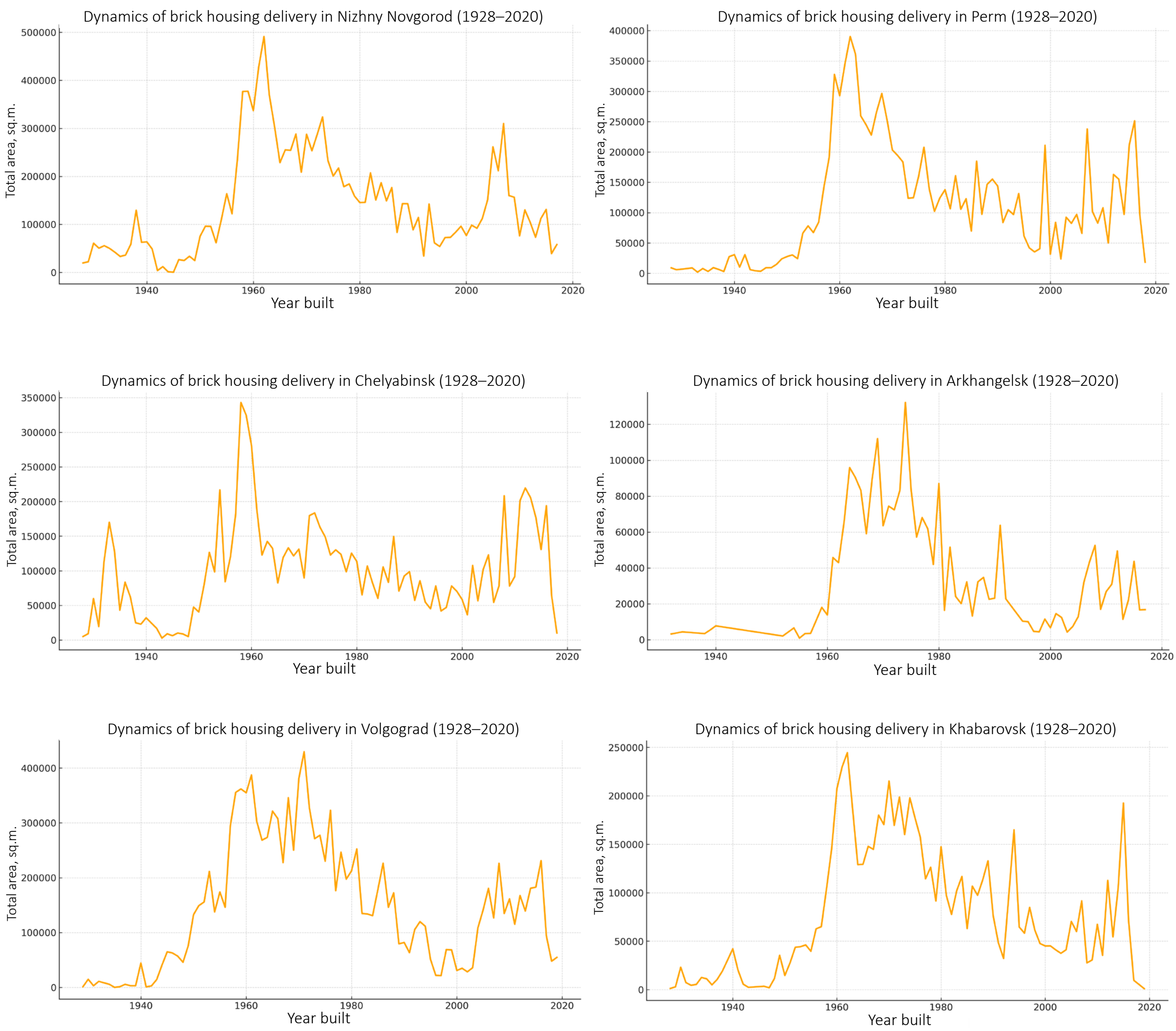


Figure 4c. The Soviet peak of brick housing construction is higher than the Russian peak

Source: own compilation.

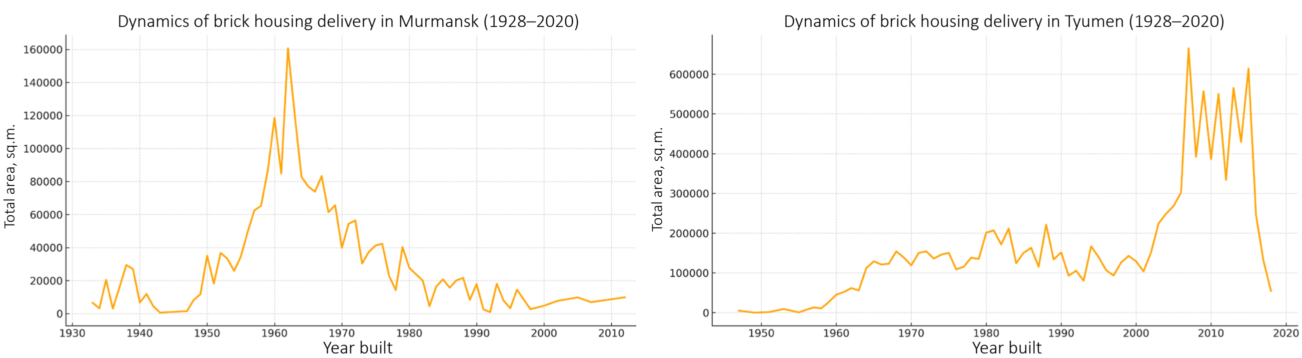


Figure 4d. There is only one Soviet or Russian peak of brick house construction

Source: own compilation.

meet the requirements of a specific economic era, leads to a paradoxical result when comparing the aggregate indicators of the annual delivery of apartment buildings. In ten cities, which is more than half of the sample cities, the share of brick housing construction in the total area of apartment buildings delivered over the entire period of analysis in the total area of all apartment buildings delivered turned out to be higher than the share of panel houses (that is, brick houses were actually collectively delivered more in total area than panel houses, despite the superactive cycle of panel housing; This can only be explained by the fact that brick houses were introduced for almost the entire period, i.e. about a hundred years, and panel houses – mainly in the half-century interval of 1960–2000; *Tab. 5*).

The difference between the leader and the trailing city is almost 2.5-fold: from the absolute dominance of brick housing in Volgograd, where it is close to two thirds of the total, to an insignificant share of a quarter in Chelyabinsk, the stronghold of panel housing. This indicates that along with the cities where the panel cycle became dominant even on the scale of an entire century, there were even more cities in the sample where it was a half-century-old "episode", which – if we consider the entire century-old period – did not abolish the dominant brick house construction, which existed massively in the third Kondratiev.

If inter-paradigm brick housing construction can be called 'enveloping" due to its presence in all the structures considered, in all economic epochs, then inter-paradigm block housing construction has an "interspersing" character in the sense that it arises during a period of need to quickly meet the need for massive cheap housing (brick is a marker of the arrival of a new paradigm, block is a marker of force majeure gigantic, sudden need for housing, for example, after the war). The top five cities with the highest share of block housing in the total number of multi-apartment buildings delivered during the analysis period included large administrative and business centers: Krasnodar (10.2%),

Table 5. The proportion of brick multi-apartment buildings in total area in the total delivery of all multi-apartment buildings, %

City	The share of brick housing in the total area of the MAH during the observation period (see Tab. 2)
Volgograd	63.4 (panel 31.4*)
Voronezh	52.4 (panel 33.8)
Samara	51.0 (panel 37.3)
Tyumen	50.5 (panel 35)
Khabarovsk	48.9 (panel 40.7)
Rostov-on-Don	48.0 (panel 38.2)
Perm	47.4 (panel 42.4)
Novosibirsk	47.2 (panel 45.5)
Nizhny Novgorod	46.2 (panel 39.7)
Krasnodar	42.6 (panel 19.3)
Omsk	40.5
Irkutsk	37.5
Vladivostok	36.5
Krasnoyarsk	34.9
Arkhangelsk	33.7
Yekaterinburg	33.6 (panel 33.8)
Murmansk	30.0
Chelyabinsk	26.1

*The proportion of panel houses is given in parentheses for reference, in cases where the proportion of brick houses exceeds it.
Source: own compilation.

Nizhny Novgorod (10.0%), Chelyabinsk (9.5%), Yekaterinburg (8.3%), Samara (4.9%).

The beginning of the era of monolithic housing construction (K5, 2010s+)

The fifth technological paradigm in housing construction is usually associated with energy-efficient technologies, digital design methods, the use of new insulation materials, the use of mixed structures, the unprecedented development of low-rise, cottage and individual construction, the design of "smart houses", etc. But for our task to trace the century-old technological evolution of the construction of multi-apartment buildings, it is essential to see in it the process of transition from the previous panel housing construction.

As evidenced by the graphs of the annual delivery of apartment buildings in our sample of Russian cities, a massive transition to the construction of monolithic houses began in the 2000s, when reinforced concrete columns and crossbars replaced the load-bearing walls. In such buildings, the load is transferred pointwise to the supports, rather than evenly over the area. Therefore, unlike the previous transition from a wooden cycle to a panel cycle (K3 to K4), the transition from a panel to a monolithic cycle (K4 to K5) was accompanied by a radical change in the foundations of multi-apartment buildings.

The girder foundation proved to be ineffective because it is designed for distributed load rather than point support elements. Builders began to apply technologies of piled foundations (especially for difficult soils and multi-story buildings) and slab foundations (solid reinforced concrete slab).

For decades, the girder foundation[9] has been effectively used in the mass construction of five- to nine-story brick and panel houses with a relatively uniform load distribution. It was ideally suited for stable soils, was simple and economical in construction, and ensured the successful development of the panel cycle in cities with "normal" soils.

However, in cities with unstable, weak, and water-saturated soils (clay, peat, and sand), piled foundations have become a necessity since the 1970s and earlier. In places with dense, rocky or loamy soils, ribbon foundations remained relevant longer, until the 2000s, when the massive development of high-rise monolithic housing construction necessitated the transition from girder to piled foundations, which became relatively more accessible due to the advent of cheaper and faster methods of pile construction (which contributed to their spread in cities, where girder foundations were previously used).

In cities with dense buildings and limited areas, piled foundations began to be used earlier, since they allow building on less suitable / weak soils (clay, quicksand, etc.). When developing urban seismically and geotechnically vulnerable areas, post foundations (concrete pillars) began to be used.

Those cities that were previously forced by natural and economic conditions to use piled, post and slab foundations, during the transition to a cycle of monolithic housing construction, unexpectedly gained an advantage in mass (multi-apartment) housing construction over those cities that used cheaper girder foundations for decades of the "wooden" and panel cycle.

In full accordance with the theory of evolution, the first monolithic apartment buildings appeared in Russian cities back in the 1930s *(Tab. 6, Fig. 5)*. However, they became a mass phenomenon in urban housing construction only in the 2000s and 2010s: what was an experiment in the 1930s and 1950s became the standard for the construction of multi-apartment buildings at the beginning of the 21st century.

In cities with strong "panel" traditions and the local panel housing lobby, the transition to a monolithic cycle was accompanied by numerous constraints, the so-called cognitive, political and functional blockages (Zamyatina, Pilyasov, 2015). It is not surprising that, according to the data in Table 6, they have not yet reached the 25 and 50 percent share of monolithic houses in the total number of

[9] A girder foundation is a reinforced concrete strip embedded in the ground running under all the load-bearing walls of a building.

Table 6. Characteristics of the beginning of the monolithic housing construction cycle in cities

City	The first monolithic house, year built	The delivery of monolithic houses accounts for 25% of the total MAH delivery, year	The delivery of monolithic houses accounts for 50% of the total MAH delivery, year	The share of the total area of monolithic houses in the total area of delivered multi-apartment buildings during the observation period, %
Irkutsk	1935	2000	2010	16.8
Vladivostok	1936	2009	2012	7.0
Samara	1949	1999	2015	6.2
Rostov-on-Don	1950	1995	Not reached	8.8
Murmansk	1959	Not reached	Not reached	0
Arkhangelsk	1959	2014	Not reached	1.2
Nizhny Novgorod	1959	2009	2018	3.0
Krasnoyarsk	1959	2017	Not reached	6.2
Tyumen	1960	2011	2014	12.2
Perm	1964	2009	2011	6.4
Novosibirsk	1971	2009	Not reached	5.8
Volgograd	1980	2011	Not reached	2.6
Omsk	1991	2019	2019	1.8
Voronezh	1994	2015	Not reached	6.0
Chelyabinsk	1994	Not reached	Not reached	1.3
Yekaterinburg	1998	2006	2012	23.9
Krasnodar	2001	2008	2008	28.0
Khabarovsk	2002	2007	2008	7.3
Source: own compilation.				

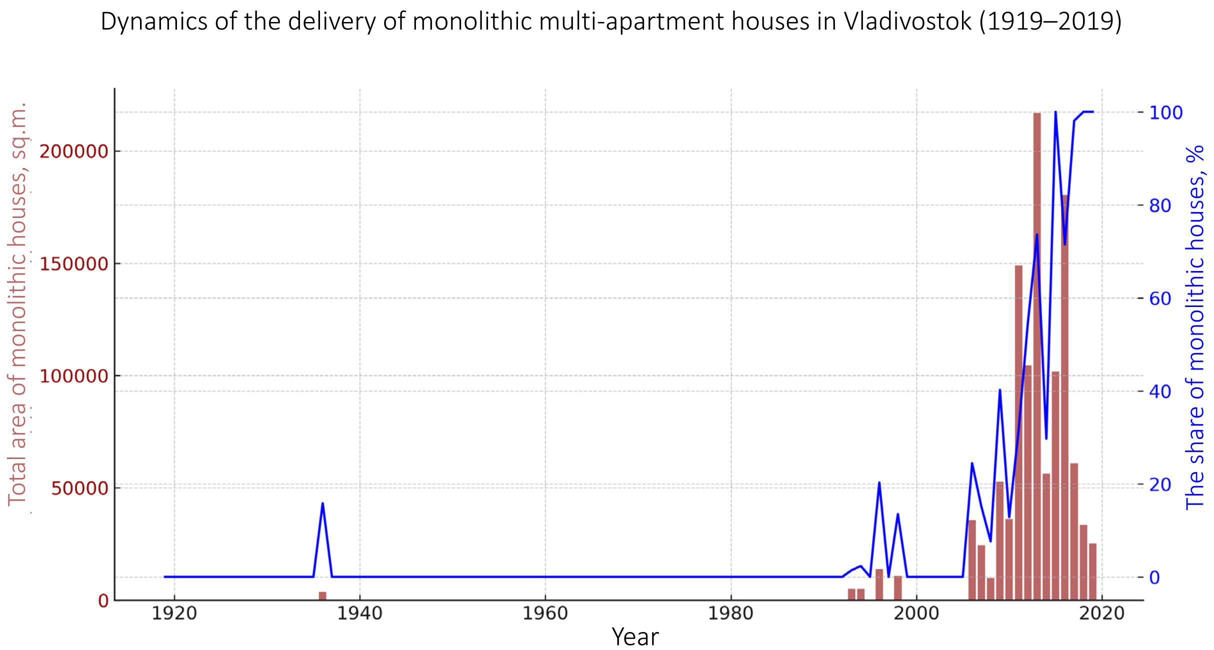


Figure 5. "Hints" of evolution in the form of the first residential monolithic houses in the 1930s

Source: own compilation.

multi-apartment buildings. All other things being equal, the transition to a monolithic cycle was easier in cities with strong previous traditions of brick housing, where there was no "panel" lobby, which did not have a strong inhibitory effect on this process.

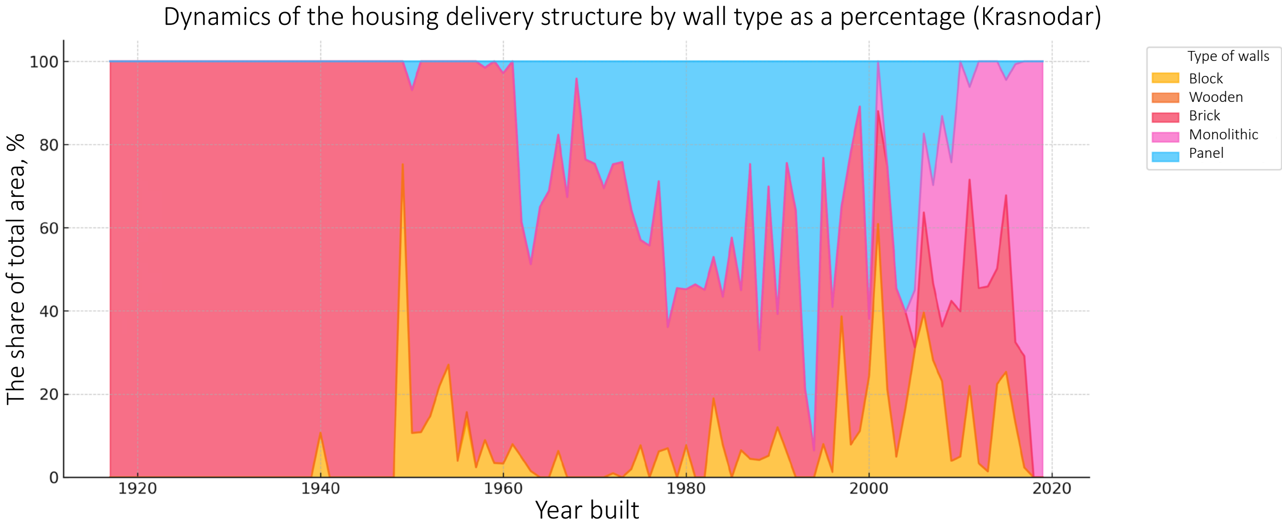


Figure 6. Krasnodar as the leader of the first phases of the monolithic housing construction cycle (the former dominance of brick housing contributes to this)

Source: own compilation.

The starting positions of cities in the first phases of the monolithic cycle are sharply uneven. There are distinct leaders – Krasnodar *(Fig. 6)* and Yekaterinburg, where the share of the total area of monolithic houses exceeds a quarter of the total area of such buildings; but there are also distinct outsiders of the technological race in housing construction, such as Murmansk, Chelyabinsk and Omsk, which can be considered as the mainstay of the former panel housing construction, and the modern share of monolithic houses in them does not exceed 2%.

An analysis of the development of a new cycle of monolithic housing construction in the context of the ongoing construction of panel and brick housing reveals a new methodological problem: how can we assess the "renaissance" of panel housing construction in the first quarter of the 21st century in many Russian cities, which belongs to the previous fourth cycle, as an inertial delay in the transition to the cycle of monolithic housing construction or as the return of panel housing construction within the already existing monolithic cycle?

This problem did not exist in the third Kondratiev, which relied mainly on wooden and brick apartment buildings at the same time (both of these wall materials became key for the construction of multi-apartment buildings in the early 20th century). It did not exist in the fourth Kondratiev, when the deployment of the panel cycle sharply brought down wooden housing construction and its "renaissance" in the next two decades in wall materials and materials of floors was very modest in terms of the total area being delivered and the share in the total delivery of apartment buildings. Brick apartment housing also declined sharply with the irruption of panel housing. In addition, as we found, it had an inter-paradigm character, stretching over its own half-century cycle through the cycles of wooden, panel and monolithic housing construction (see Fig. 4).

However, with the beginning of the monolithic cycle, panel housing in many cities, after a short crisis in the early 2000s, sharply increased both in volume and share in total area of multi-apartment buildings delivered. How to interpret this unexpected phenomenon?

To diagnose the situation, we suggest using three criteria at the same time: 1) the volume of delivery of the total area of panel housing in comparison with the canonical period of the full deployment of the panel cycle in the 1960s–2000s: if they repeat or exceed the absolute volumes of the Soviet era, then this may be a necessary (but insufficient) condition to attribute the new growth in panel housing production at the beginning of the 21st century to the prolongation of the panel cycle; 2) the dynamics of the share of panel housing in the delivery of the total area of all multi-apartment buildings: if these volumes over the period of the 2010s years, after the "official" end of the panel cycle, were equal to or exceeded 50% several times, then we can describe this situation as an obvious prolongation of the panel cycle; 3) the share of monolithic housing – if it has never reached 50% in the 2010s years (Tab. 6), then we should be talking about a prolongation of the panel cycle, and not about the beginning of a new monolithic cycle.

After using all three criteria, we have a tool for distinguishing the effects of the prolongation of the panel cycle and the effects of the return (renaissance) of panel housing construction within the first phase of the monolithic cycle (K5.1): Chelyabinsk, Krasnoyarsk, Novosibirsk, Voronezh – the prolongation effects of the panel cycle in the first quarter of the 21st century; Omsk and Tyumen – the renaissance of panel housing within the already existing monolithic cycle. *Figure 7* clearly shows the difference between the profiles of panel housing construction in the 21st century in cities with the prolongation effect and the return effect – Krasnoyarsk and Tyumen.

An even more difficult methodological problem arises when assessing the nature of block housing in the first quarter of the 21st century. Modern block houses can be considered as a development of the panel housing construction line while maintaining the basic features of the fourth technological structure in multi-apartment housing (factory manufacturing of elements and their assembly on site). If new block technologies are accompanied by improved build quality, more complex architectural solutions and increased energy efficiency, they can be considered as a transitional version to a new monolithic phase.

Unfortunately, the indicators of our database (Tab. 1, Fig. 1) do not provide an opportunity to clearly distinguish the nature of the new block housing construction of the 21st century into the first and second types. The same problems arise with reinforced concrete walls: if they are made of prefabricated panels, they belong to K4, if they are monolithic, then to K5. The database features do not allow us to diagnose the case as well.

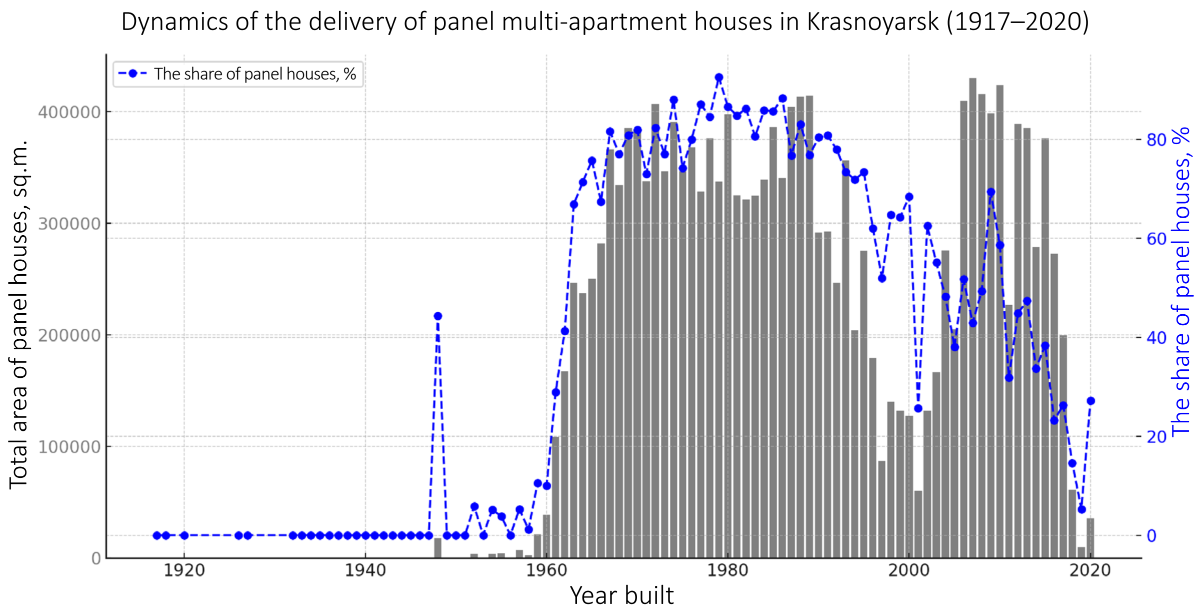
It can be concluded that the transition to a monolithic cycle in multi-apartment housing raises new important methodological issues associated with the increasing variety of "wall" modifications of apartment buildings, including hybrid materials used (for example, frame-monolithic), and the traditional classification (wooden, brick, block, panel, monolithic) simply does not cover them. In addition, the share of cottage, low-rise, and individual residential buildings, rather than multi-apartment buildings, is increasing, i.e. the share and importance of multi-apartment housing (in some cities very significantly) are decreasing.

Three types of cities in terms of transition to K5

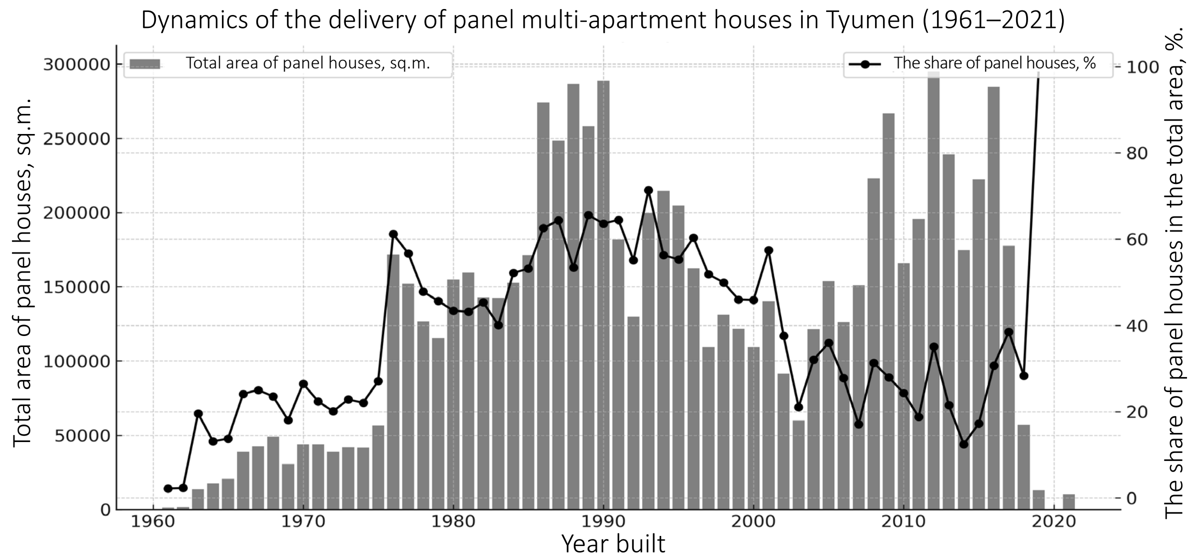
The data we have on a sample of 18 cities allows us to diagnose a specific phase in the spirit of the Kondratiev – Perez – Glazyev long wave concept (K5.1 irruption phase, K5.2 frenzy phase, K4.3 synergy phase, K4.4 maturity phase) for the fourth panel or fifth monolithic cycle, which every city is currently in. For the typology of cities, we used five indicators obtained on the basis of visual and quantitative analysis of indicators of the annual dynamics of the delivery of the total area of multi-apartment buildings by types of walls, foundations in a hundred-year retrospect.

1. The volume of monolithic housing construction and their average share in the last 30 years in the total for the entire period of monitoring the delivery of the total area of apartment buildings. The transition to monolithic housing construction indicates a qualitative technological shift. Monolithic structures have greater flexibility in design, better thermal insulation, energy efficiency, and the ability to increase the number of floors. This coincides with the general trends of the fifth technological order, which is based on new building materials, automated technologies and digital design.

2. Were there any radical changes in the structure of foundations in the 2000s? The leading cities of the new technological order in housing construction are distinguished by the



a) The manifestation of the effect of the prolongation of the cycle of panel housing construction



b) The manifestation of the effect of the return of panel housing within the first phase of the monolithic cycle

Figure 7. The difference in the dynamics profiles of panel housing construction in cities with the effect of a) prolongation (Krasnoyarsk) and b) return (Tyumen)

Source: own compilation.

rapid displacement of girder foundations by piled, spread foundations, and concrete pillars in the last two to three decades due to the transition to monolithic housing construction and new technologies for multi-story construction (above the traditional nine floors). In cities with more sluggish development, the dominance of girder is noted, with the gradual addition of a proportion of piled, spread foundations and concrete pillars. Some cities with unstable soils are characterized by the forced displacement of girder foundations by piled foundations back in Soviet times.

3. Comparison of the volumes of the first Soviet and second Russian peaks of total delivery of the total area. The ratio of the first and second peaks indicates the exact time when the technology of housing construction became really popular and massive in the city – in K4 or in K5. If the second Russian

peak is higher and it is caused not by panel construction, but monolithic and brick housing (which is accompanied by a change in the types of foundations), then we can state a radical technological shift, not inertial modernization.

4. Comparison between the first and second peaks of brick housing construction. Among the cities leading the technological transition, the Russian peak is expected to be significantly higher than the Soviet one. Among the average performers, the Soviet peak is higher or comparable to the Russian one. And among the outsiders of the technological race, the Soviet peak is significantly higher than the Russian one.

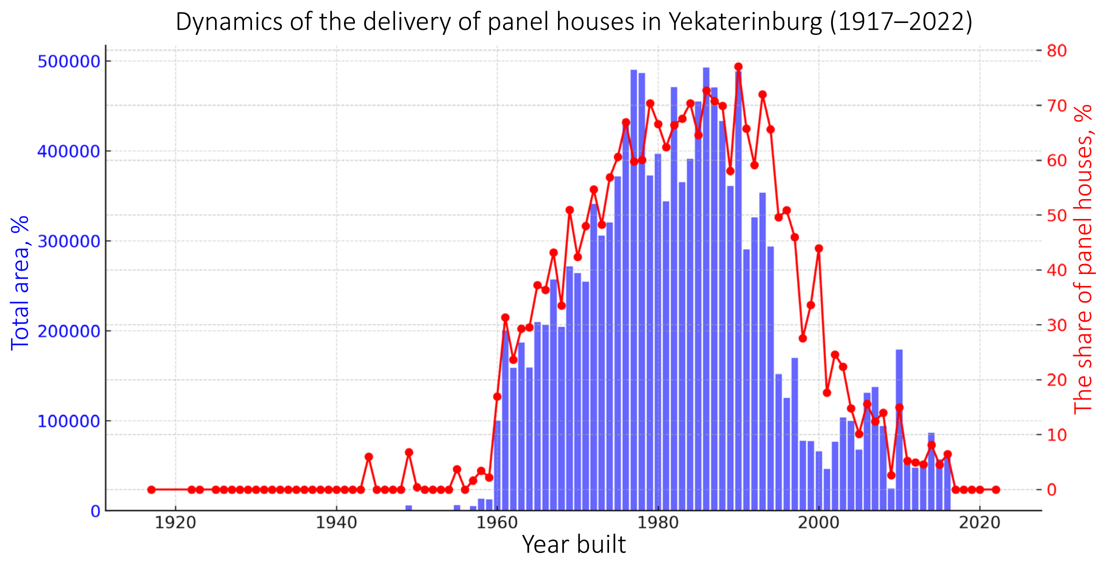
5. Was there a renaissance of panel housing in the 2000s? The return of panel housing construction, with the distinction between the prolongation and return effects, makes it possible to identify the leaders of the transition to a new paradigm (they have a return of panel housing within a monolithic cycle) and outsider cities (they have a dominant prolongation effect). For a clearer understanding of the specific phases K4 and K5 of the city, it is necessary to attract additional information about the main real estate developers, their organizational form and ownership structure, information about economic and organizational factors affecting the speed of technological evolution in urban housing construction. Therefore, our typology *(Tab. 7)* has a general, preliminary character as of the beginning of the 2020s, for which the latest data were available.

Let us take a closer look at the example of the Ural cities of Yekaterinburg, Perm and Chelyabinsk, interesting because each of them falls into its own characteristic type of our classification – the first, second and third. Yekaterinburg clearly marks the time limits of the last cycle of panel housing construction – from 1958 to 2015, i.e. about 65 years, with complete displacement at the end *(Fig. 8)*. Using the example of the dynamics graph of an average panel house size, four phases of the K4 panel wave are visible: K4.1 – irruption phase (1958–1965); K4.2 – frenzy phase (1966–1979); transition period (1980–1987); K4.3 – golden age (1987–2000); K4.4 – depletion (2000–2016), i.e. a sharp drop in the share and then in the volume of annual delivery of multi-apartment panel total area.

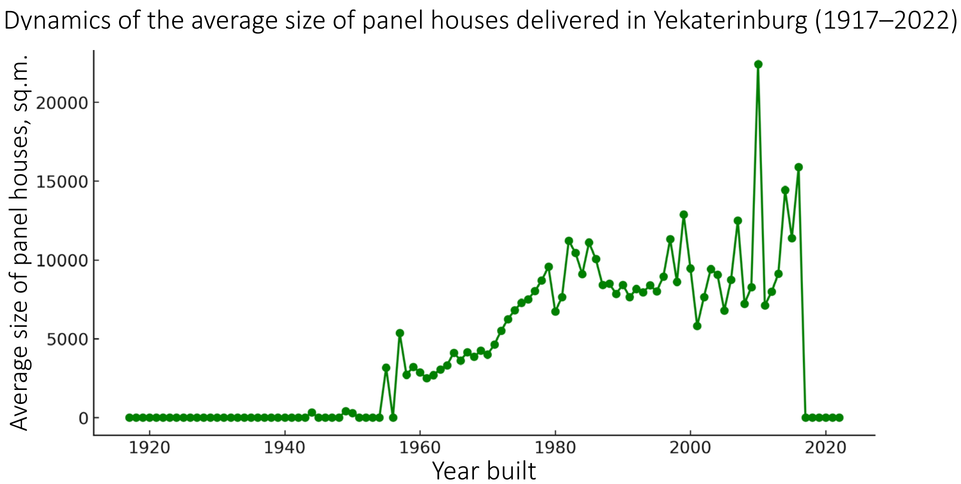
The first monolithic house in Yekaterinburg was built back in 1959. In the 1980s, active experimentation with monolithic housing began, and from 2000 to 2018, continuous

Table 7. The typology of cities in terms of the activity of transition to a new technological paradigm in multi-apartment housing

Type	List of cities	Phase	Description
First group	Krasnodar Yekaterinburg Irkutsk Tyumen	K 5.1.–5.2. Irruption and frenzy phases of monolithic housing construction	Leaders of technological development, the Russian peak of annual delivery of multi-apartment buildings is significantly higher than the Soviet one due to monolithic and brick housing construction
Polarized pattern, transitioning from type 1 to type 2	Rostov-on-Don Khabarovsk Vladivostok	K 5.1. Irruption phase of monolithic housing construction	Active introduction of monolithic, brick housing construction
Second group	Perm Krasnoyarsk Samara Voronezh Novosibirsk	K 4.4–5.1. Saturation of panel construction and irruption phase of monolithic housing construction	The Russian peak is comparable to the Soviet one. The return of significant volumes of panel housing construction (strong traditions of industrial housing construction) within the monolithic housing construction that begins to develop
Third group	Nizhny Novgorod Volgograd Omsk Chelyabinsk Arkhangelsk Murmansk	K 4.4. Saturation of panel construction	The Soviet peak is higher than the Russian one. The prolongation of panel housing construction in the 21st century with the complete absence or a minimum proportion (less than 3%) of monolithic housing construction
Source: own compilation.			



a) Dynamics of panel housing delivery by total area, sq.m.



b) Dynamics of the average size of panel housing, sq.m.

Figure 8. The cycle of panel housing construction in Yekaterinburg: a) the dynamics of panel housing delivery by total area; b) the dynamics of the average size of panel housing

Source: own compilation.

delivery with growth. In some years, monolithic houses accounted for up to 100% of the total number of apartment buildings. From 2000 to 2018, the average size of a monolithic house grew to 25,000 m^2.

Yekaterinburg has moved far in the cycle of monolithic housing construction *(Fig. 9)*. It is probably in the second phase of the cycle – frenzy investment, in the terminology of C. Perez. As a metropolis, the city has significant investment resources for a dynamic transition from a panel to a monolithic cycle.

Since 2000, the girder foundation has been displaced there by piled and spread foundations. The city switched to piled soils and concrete pillars from girder later than many other large cities. However, due to the large-scale volumes of new construction in the first quarter of the 21st century, it quickly overcame this lag.

A special feature of Yekaterinburg is the historically significant (and greater than in other Ural cities) role of block housing, which is explained by the following reasons: 1) during the period of industrial growth, the need for rapid housing development of thousands of employees of new factories explains the appeal to quick solutions in housing construction, which was provided

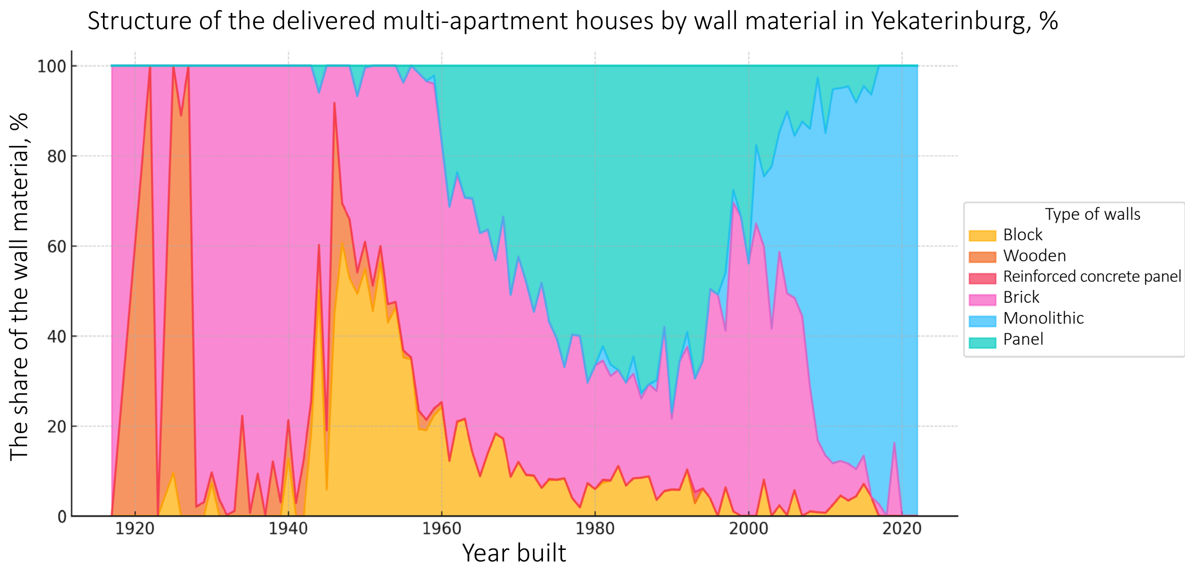


Figure 9. The cycle of monolithic housing construction in Yekaterinburg

Source: own compilation.

by block housing construction (large housing construction plants operated in Yekaterinburg, supplying blocks and panels for mass construction); 2) Yekaterinburg is located in a climatic zone with long winters, and the use of block structures made it possible to quickly erect buildings, reducing construction time during the cold period.

Perm is obviously lagging behind Yekaterinburg in moving along the monolithic cycle, not only in terms of delivery volumes (Perm is smaller), but also in terms of structure – Yekaterinburg has a higher proportion of monolithic houses, and they are getting rid of panel housing faster. But Perm repeated Yekaterinburg with a slight delay in both the wooden and brick cycles.

Apparently, its phase K5.1 is an irruption phase. The share of monolithic housing in the total area of apartment buildings in the last two decades has ranged from 20 to 80 in some years. After experimenting with monoliths in the 1960s and 1990s, active construction of monolithic housing began from 2008 to 2018. The urban planning policy there was not as clearly focused on mass construction of block houses as in Yekaterinburg *(Fig. 10)*.

Perm is located in a wetter climate, with more difficult soil conditions than Yekaterinburg, so earlier, back in the 1970s, it abandoned girder foundations and switched to piled foundations *(Fig. 11)*.

Chelyabinsk, the Russian stronghold of panel housing construction, is still in the last phase of the fourth cycle, with obvious prolongation effects *(Fig. 12)*. The entire period of 1960–2020 was characterized by the unconditional dominance of panel housing construction both in terms of delivery volumes and its share in the total delivery of multi-apartment buildings in the city. The share of monolithic housing construction has been less than 10% in recent years. With great delay, compared to other cities, the transition from girder to piled foundations has begun there only since the 2000s *(Fig. 13)*.

The hyperindustriality of Chelyabinsk in comparison with Yekaterinburg, which is the administrative center, and Perm, which has more diverse structure of the economy, determined its “overstaying” on the panel cycle. At the same time, the average size of a panel house has been decreasing since the 1990s due to the transition to the construction of new, more comfortable and energy-efficient, mass-produced series. Compared to the other two Ural cities, Chelyabinsk has the most compact panel houses. Similar trends can be found in brick housing construction: the largest brick houses are typical for Yekaterinburg, the

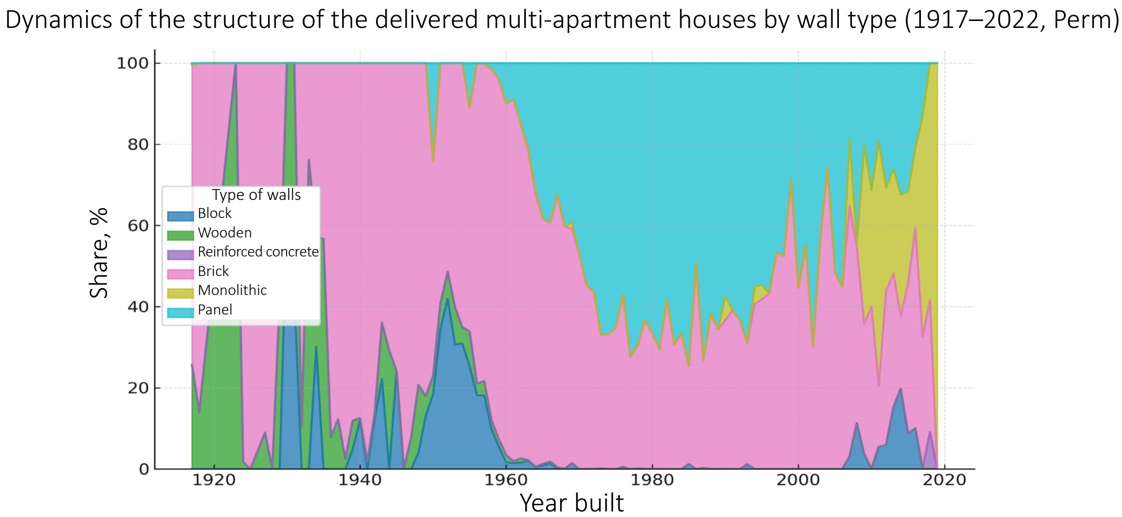


Figure 10. The specifics of Perm: modest volumes of monolithic housing construction, traditions of brick housing construction, the displacement of panel housing in the delivery of the total area in recent years, a modest proportion of the construction of block housing

Source: own compilation.

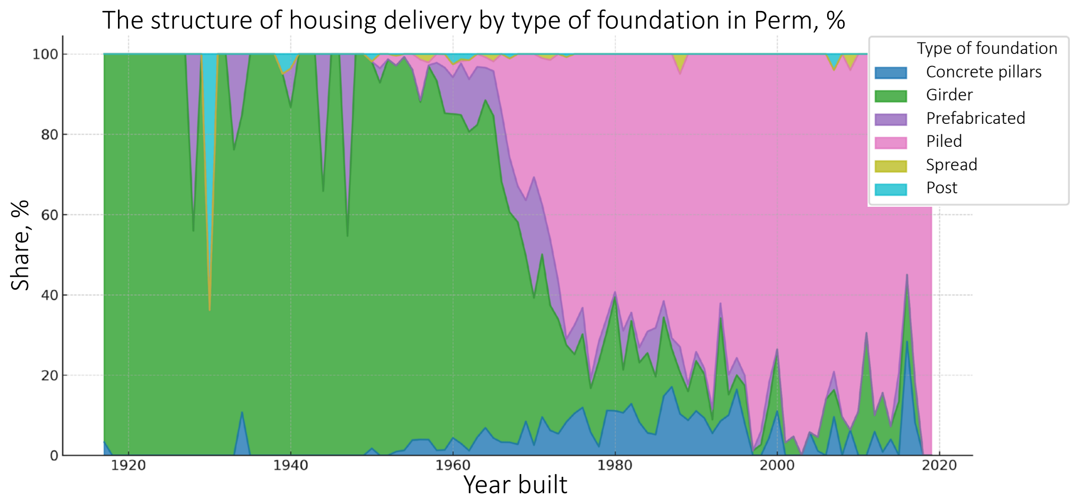


Figure 11. Early displacement of girder foundations in Perm is the result of difficult soil conditions for multi-story residential construction

Source: own compilation.

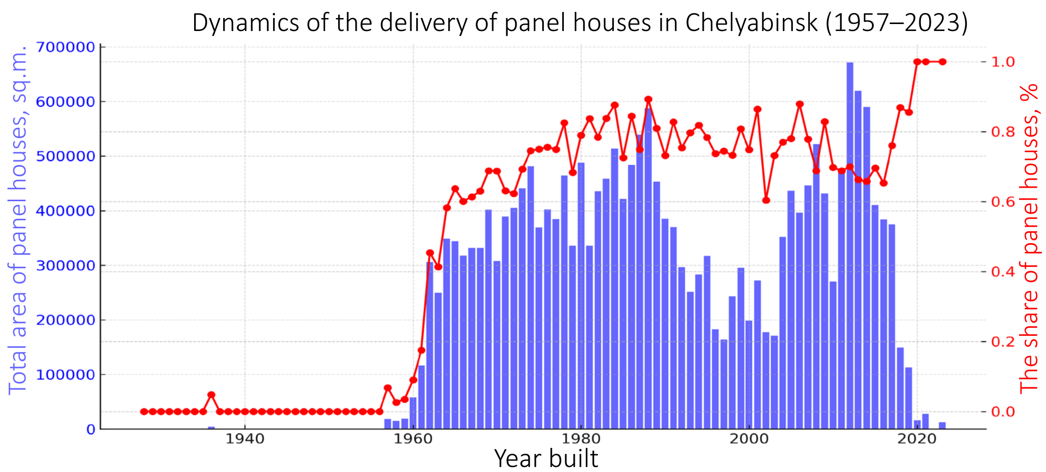


Figure 12. Prolongation of the panel cycle in Chelyabinsk

Source: own compilation.

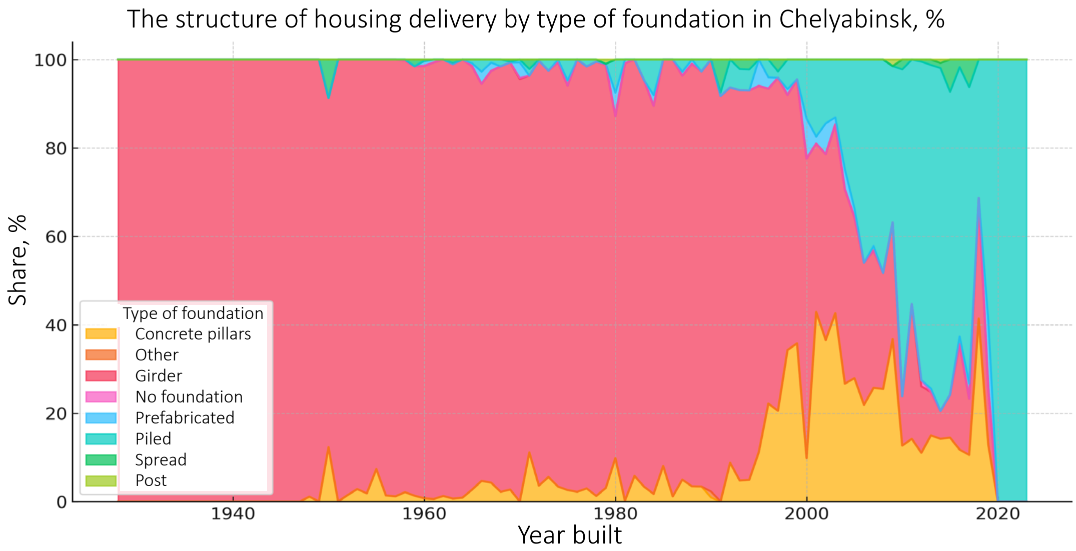


Figure 13. Late, delayed transition of housing construction in Chelyabinsk from girder to piled foundations

Source: own compilation.

smallest among the three Ural cities are in Chelyabinsk.

The administrative status and investment opportunities of the Ural capital have determined Yekaterinburg's leading positions in technological evolution. Perm's economic diversity and rich pre-industrial (cultural and other) traditions allowed the city to overcome the dominance of industrial panel housing relatively quickly and enter the first phase of a monolithic cycle. On the other hand, Chelyabinsk's significant industrial "mono-profile" has determined its long-term "overstaying" in the final phase of the panel housing construction cycle.

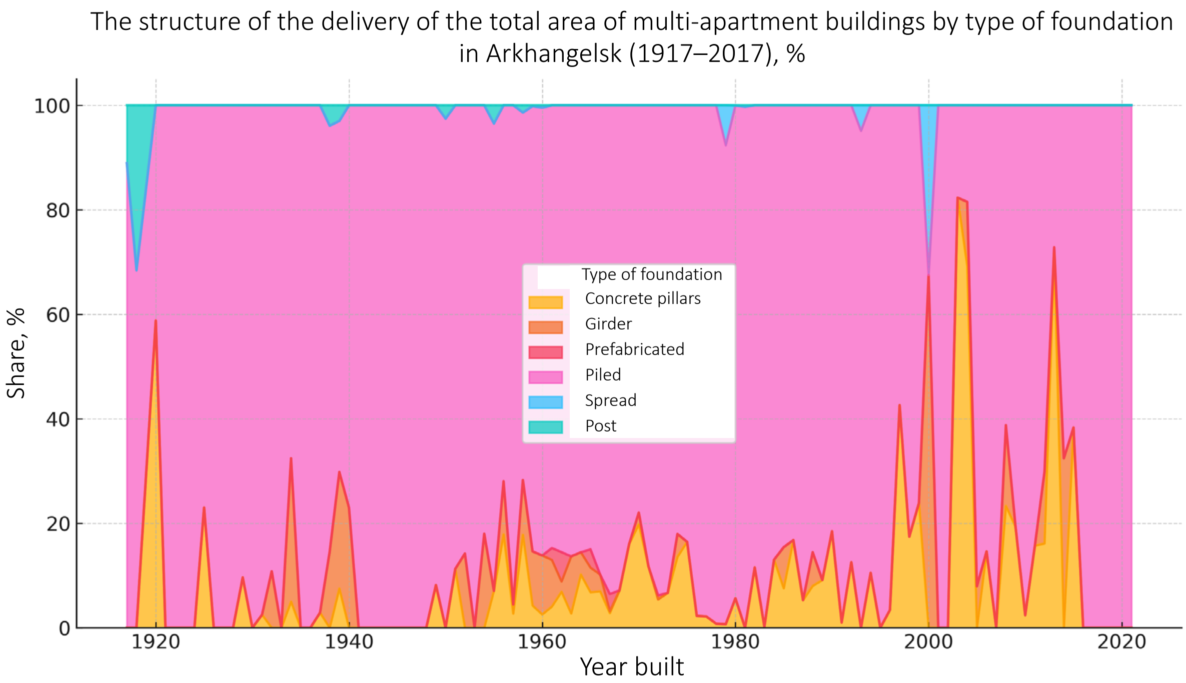
Factors of technological dynamics: comparison of analog cities

To identify various factors (natural, historical, economic, and institutional/organizational) affecting the speed of technological evolution of the studied cities, the method of comparative analysis of similar cities was used. What was discovered?

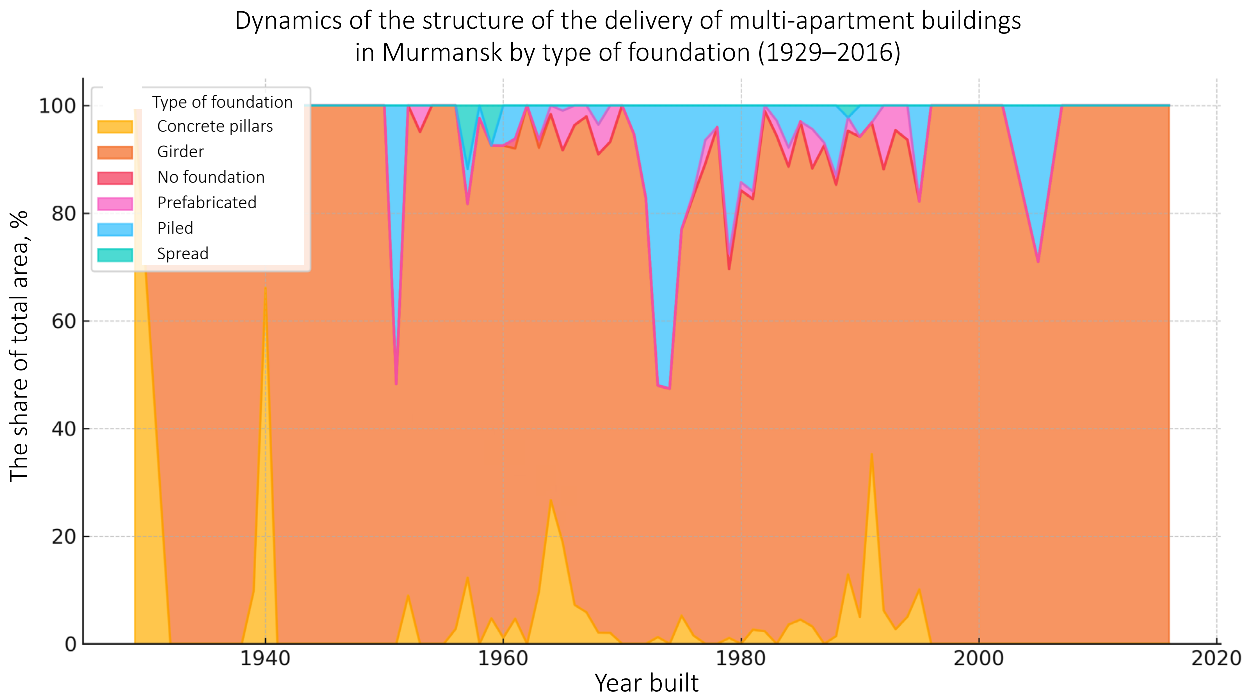
Historically established and naturally conditioned circumstances of the development of multi-apartment housing construction can in one case work to accelerate its technological transformation, and in the other – to slow it down. They play a dual role in technological dynamics, which is confirmed by the comparison of two Arctic cities of comparable size – Arkhangelsk and Murmansk.

Historically, since the time of wooden housing construction, the dominance of piled foundations, rather than girder, as in Murmansk, which are organic for monolithic housing construction, became a factor in the early transition to high-rise apartment construction. In Arkhangelsk, "weak" (swampy, peat, and water-saturated) soils are common, which makes a piled foundation a more reliable and economically advantageous solution. Therefore, for a quick transition to the first phase of the monolithic cycle, Arkhangelsk had the advantages of a long-established "historical track", originated from the disadvantages and natural limitations of local soils.

On the other hand, the inherited monopoly of girder foundations on "strong" soils in Murmansk proved to be a brake on the transition to multi-apartment construction using new technologies *(Fig. 14)*. In Murmansk, rocky soils predominate, which have a high bearing capacity, therefore, girder foundations were more practical and economical there. The construction of a piled foundation in rocky soils requires significant costs, since piles have to be driven or drilled into solid rock. It is not surprising that throughout the panel cycle, the average size of a panel (as well as brick) house in Murmansk was smaller than in Arkhangelsk,



a) Arkhangelsk – dominance of piled foundations



b) Murmansk – dominance of girder foundations

Figure 14. The differences of "path dependence"

Note: in the case of Arkhangelsk, the historical dominance of piled foundations helps to transition to multi-story monolithic housing construction (Fig. 14a), in the case of Murmansk, the historical dominance of girder foundations prolongs the panel cycle of medium-rise (five to nine floors) housing construction (Fig. 14b).

Source: own compilation.

due to the inability to build multi-story houses on the dominant girder foundations there.

It is incorrect to assume that the leaders of the previous technological era automatically receive "trump cards" when switching to a new technological order. On the contrary, those who lag behind during the change of paradigms, without the burden of their former dependence, get a chance to get ahead – but only with strong investment support. A comparison of the technological dynamics in the multi-apartment housing construction in Krasnodar and Rostov-on-Don clearly demonstrates that cities that lag behind in the K4 panel cycle can become leaders in the monolithic K5 cycle and often do it.

Historically, there has not been an absolute monopoly of panel housing in Krasnodar – the share of brick in the delivery of the total area of multi-apartment residential buildings was often 50+% (brick, like individual residential construction, effectively competed with panel housing there). This is not surprising, since Krasnodar has long developed as an agricultural and recreational city with low-rise buildings, while Rostov-on-Don was a major industrial and transport center. Mechanical engineering, metallurgy and the construction industry were actively developing in the city, which made it possible to use the most advanced methods of panel construction.

However, an advantage in the "panel" era became a disadvantage in the era of monolithic multi-apartment housing, and vice versa, the lower bar for the development of panel housing in Krasnodar than in Rostov unexpectedly contributed to a quick transition to a new monolithic cycle. Since the 2000s, Krasnodar has experienced an active (almost 5-fold in a short period) increase in the construction of multi-story residential complexes, primarily monolithic, but also brick and block. On the other hand, in Rostov-on-Don, despite the earlier start of construction of the first monolithic houses, significant volumes of panel housing construction still remain.

It is necessary to distinguish between "close" (25–50 years old) and "far" (50–75 years old) traditions that have different influence on the success of technological modernization. Close traditions are a factor of inertial conservation of the previous paradigm and a brake on technological modernization; on the other hand, far traditions are a source of modern innovation, a factor for reducing the influence of the previous paradigm and its constraints in the form of, for example, the "panel" local construction lobby on modern technological development. For example, the traditions of wooden housing construction, due to natural conditions in the form of soil type, climate, and availability of wood resources, often determined the relatively weaker development of the next panel cycle compared to other cities where such traditions did not exist, which, in turn, affected a faster transition to the monolithic housing cycle. Roughly speaking, there are "good" traditions that help the technological modernization of housing construction, and there are "bad" traditions that slow it down.

Let us compare the development of multi-apartment housing in three cities situated on the Volga – Samara, Nizhny Novgorod and Volgograd. In Samara, the era of wooden housing was actively manifested in the construction of multi-apartment buildings until the early 1950s (it accounted for up to 80% of the total area of multi-apartment buildings being delivered against the background of generally insignificant delivery volumes). The city has retained the dominance of girder foundations due to a combination of geological, economic and technological factors. Historically, there were strong traditions of low-rise individual housing there, and the panel cycle was relatively shorter and less pronounced than in Nizhny Novgorod, with the brick housing cycle becoming the mainstay.

It is clear that new things can be implemented easier when there are no strong traditions of the recent past technological cycle. But in fact, the real situation is more complicated. Samara still has a small proportion of monolithic housing construction, and the delivery of brick apartment buildings by local construction firms on traditional girder foundations is absolutely dominant, which ensured the city's leadership over two other Volga cities in the first two decades of the 21st century *(Fig. 15)*.

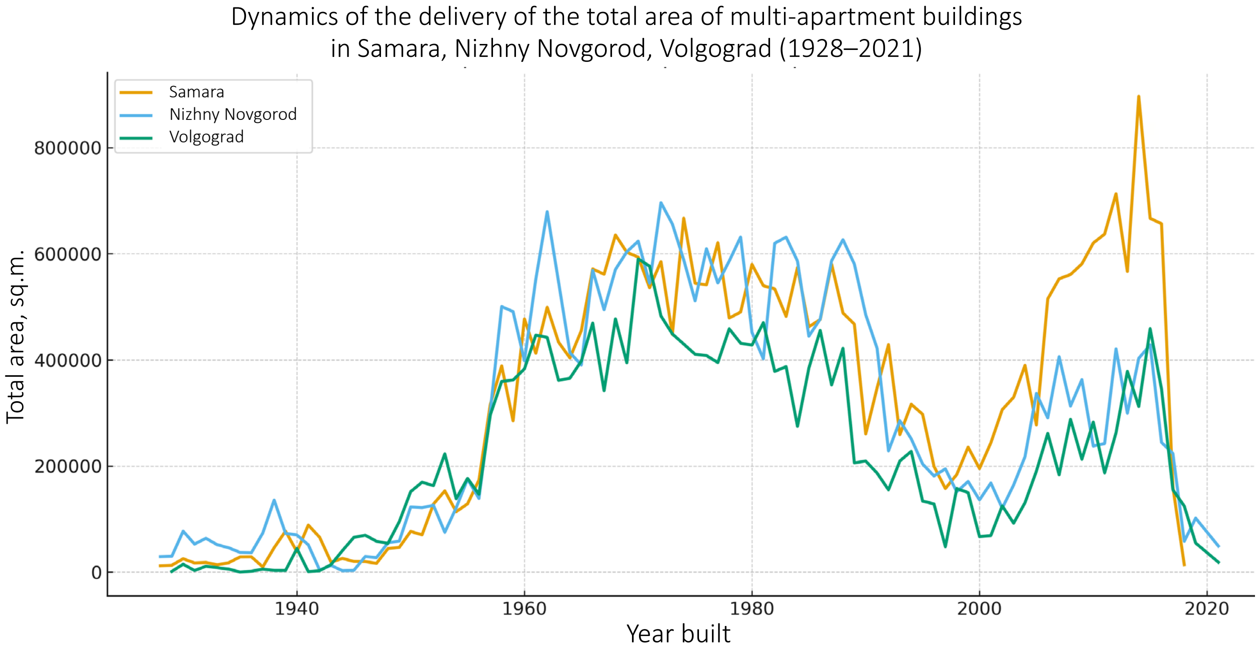


Figure 15. Delivery of the total area of multi-apartment buildings in Samara, Nizhny Novgorod, Volgograd in a hundred-year retrospect

Source: own compilation.

In most segments, the leaders of Samara and Nizhny Novgorod alternated; Volgograd, after leading for the first decades, traditionally lagged behind. In Volgograd, the share of individual residential construction has been up to 35% of the total housing delivery in recent years (data from the Institute for Urban Economics), which determines the city's low positions in the delivery of the total area of multi-apartment housing.

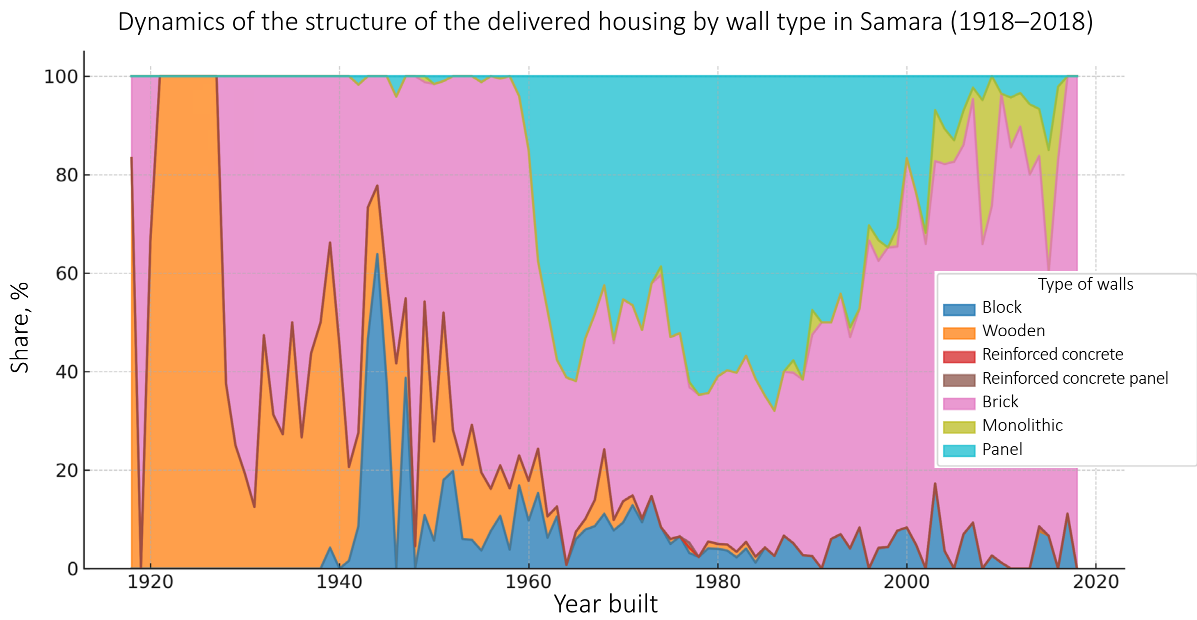
In Samara, soils favorable for girder foundations prevail: sandy, loamy, characterized by the presence of stable soil layers at relatively shallow depths. This allows the use of girder foundations without significant risks of precipitation or deformation.

The situation is different in Nizhny Novgorod and Volgograd. In Nizhny Novgorod, the soils are more water-saturated, in Volgograd there are collapsible loess soils that require piled or slab foundations. Therefore, since the beginning of the 2000s, there has been a shift away from the dominance of girder foundations in the construction of multi-apartment buildings (which did not happen in Samara).

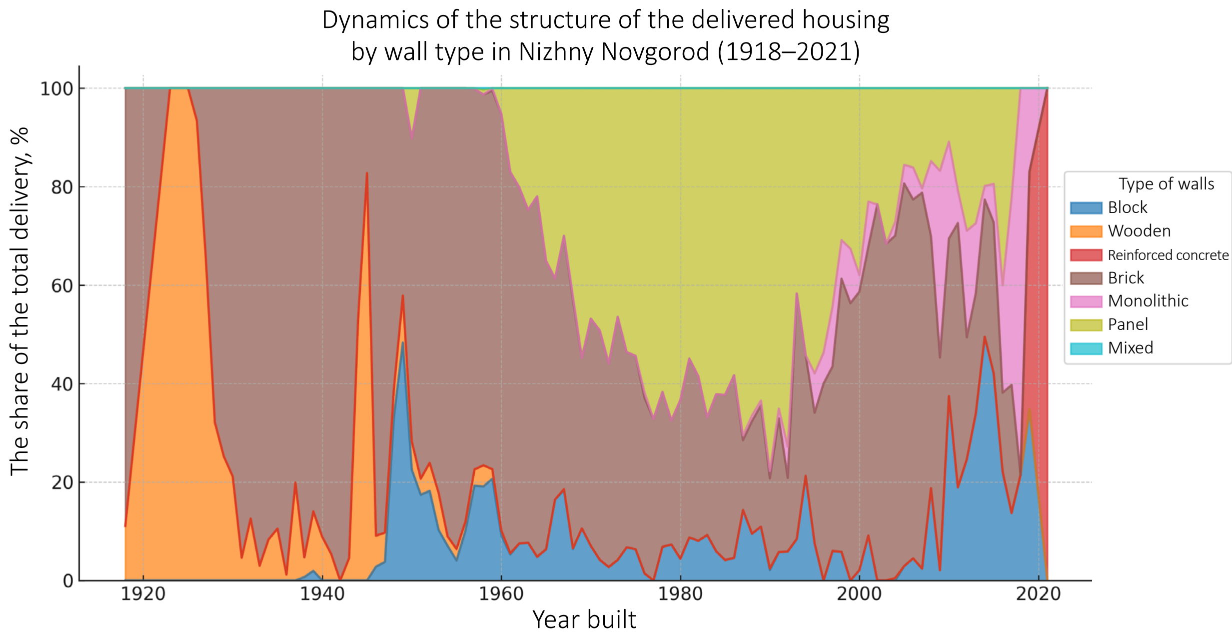
In Samara, a significant part of the construction is carried out by local companies that prefer to use previously mastered and familiar technologies of brick house construction, which do not require additional costs for retraining workers and re-equipping enterprises. On the other hand, in Nizhny Novgorod and Volgograd in the 1990s and the first decades of the 21st century, large developers were widely involved in construction, investing in more technologically advanced construction methods. This led to the abandonment of girder foundations in favor of piled and slab foundations.

Therefore, Samara's leadership in the volume of general delivery of multi-apartment housing is actually provided not by new construction methods of the monolithic cycle era, but by the old technologies and materials of brick house construction and girder foundations, compared with smaller volumes of multi-apartment buildings, for example, in Nizhny Novgorod, but with a more diverse and modern structure of walls and foundations *(Fig. 16)*.

The city's leadership in modern total volumes of multi-apartment housing does not always mean that it is technologically advanced in the phases of the monolithic housing construction cycle. Samara, being the



a) Samara



b) Nizhny Novgorod

Figure 16. Comparison of the dynamics of the delivery structure of multi-apartment buildings by type of walls

Source: own compilation.

leader in housing delivery, provides it through traditional brick housing construction based on traditional girder foundations; on the other hand, Nizhny Novgorod, lagging behind Samara in total volumes (the Soviet peak here is significantly higher than the Russian one), provides buildings with a significantly more modern wall structure and types of foundations.

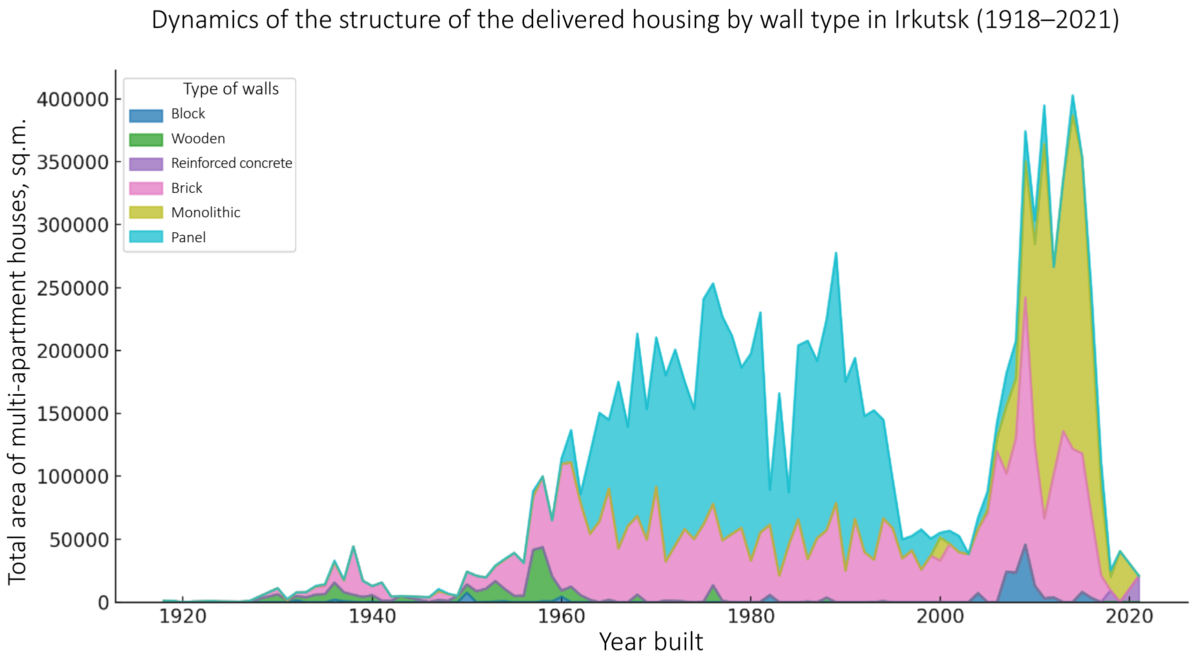
A comparison of the speed of technological dynamics of multi-apartment housing construction in three Volga cities reveals the significant role of large external developers in introducing advanced practices of monolithic housing construction and the associated rapid transition to piled, spread and other new types of foundations (instead of the girder foundation traditional in many cities). So, in cities where constrains for new developers are developed and the monopoly of small local developers remains, conditions are being created for the conservation and long-term inertial reproduction of the close traditions of panel housing construction.

The underdevelopment of industrial panel housing and the panel cycle was often combined in the city with the hyper-development of brick housing and then created the best conditions for the rapid development of the monolithic cycle. In this sense, we can say that Irkutsk, Tyumen and Krasnodar have common technological evolution paths: they did not have a strong panel housing construction, a strong lobby of old house-building plants, and therefore the monolithic cycle in conditions of significant amounts of financing (which, however, could have been used to consolidate the previous panel era) progressed faster and easier *(Fig. 17)*.

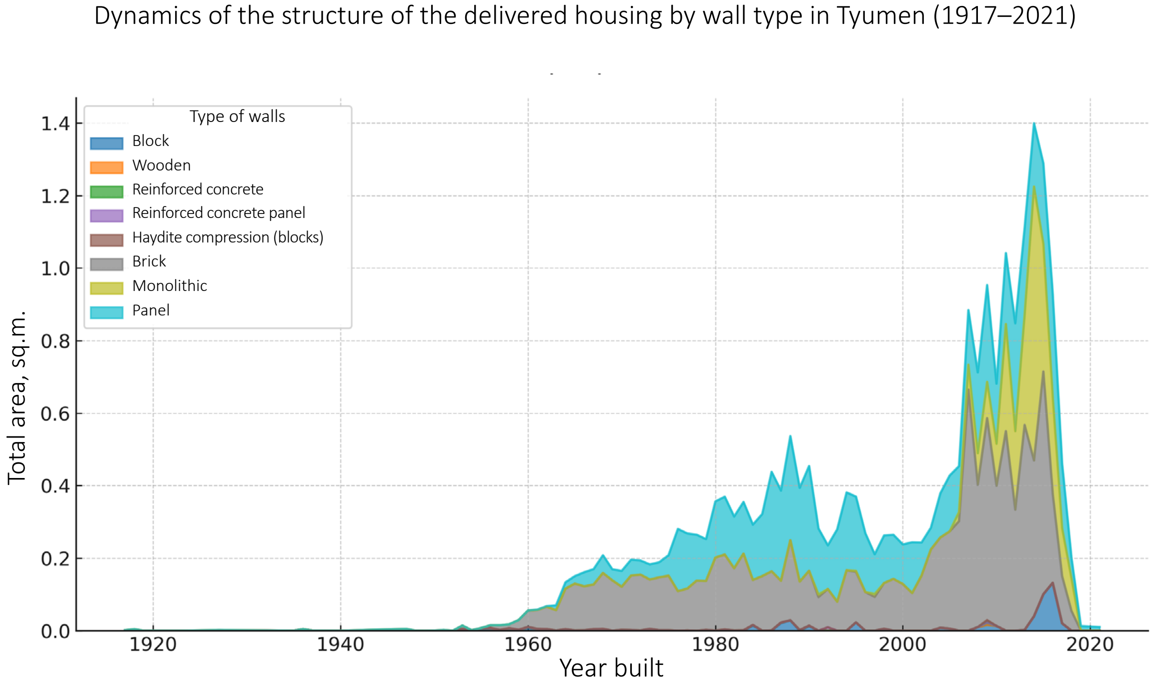
Cities that received large-scale investment resources for multi-apartment housing in the first two decades of the 21st century had a choice between developing (which automatically means prolonging) the panel cycle or moving to the deployment of the first phases of the monolithic cycle. The specific trajectory chosen depended on a local combination of several conditions: the strength of the traditions of panel housing construction, determined by the preservation of old house-building complexes, the lobby of local developers, the overall scale and volume of panel cycle development during the Soviet era; the existing structure of the foundations of multi-apartment buildings at the time of selection (if girder dominated, the transition to K5 was more difficult or delayed; if piled, spread foundations, etc. dominated, favorable prerequisites arose for the transition to K5); the historical development of wooden and brick housing construction in the city, preserved traditions of individual residential construction, which generally meant the short panel cycle and therefore indirectly worked for an easier and faster irruption of the monolithic cycle. Irkutsk, Tyumen and Krasnodar are the examples of the significant role of these factors in the beginning of monolithic housing construction.

Discussion of the results

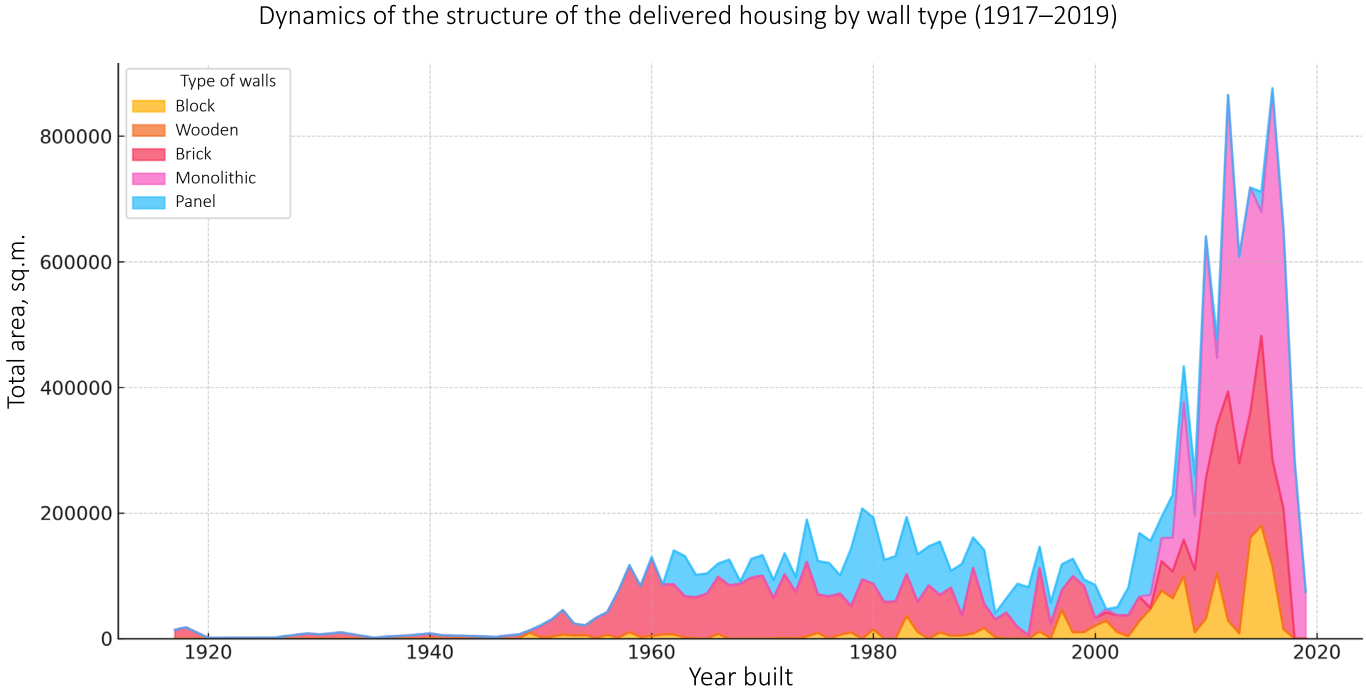
The approach implemented in this paper is naturally not free from drawbacks. The very first discussion, held at the Leontief Readings at the Leontief Center in St Petersburg, identified



a) Irkutsk



b) Tyumen



c) Krasnodar

Figure 17. Dynamics of the structure of the multi-apartment housing delivery by types of walls

Note: The overall significant growth is presented in the context of a significant evolution of the wall structure: a) Irkutsk – the rapid displacement of panel construction at the beginning of the 21st century and the increasing role of monolithic housing construction; b) Tyumen – the comparable development of monolithic and panel housing in recent decades (25–30% each) with the dominant role of brick (about 50%); c) Krasnodar has experienced multiple growth in the last 15 years due to the active development of monolithic housing construction.

Source: own compilation.

three main lines of criticism. First, actually, in a hundred-year retrospect, only the panel cycle K4 is most clearly marked, and the wooden/ brick K3 and monolithic K5 are only outlined, and it is premature to speak firmly about the half-century-old patterns of "long waves" here. We are grateful to our colleague, Candidate of Sciences (Geography) N.Yu. Zamyatina, who identified this vulnerability of our work.

In fact, in all cities we clearly diagnosed a panel cycle, which is certainly tied to the technological structure of K4, and an inter-paradigm, but also half-century-old, brick cycle, which manifests itself in all the cities studied, but does not have a distinct technological link to a specific economic epoch. On the one hand, the unreliability of data before 1917 does not allow us to see the development of the wooden-brick cycle K3; on the other hand, the early K3 does not have those features of mass character and new efficiency that are crucial for the deployment of any Kondratiev technological cycle (which means that the realities that are observed in the annual dynamics of the delivery of multi-apartment buildings in the studied cities of the first two decades of the 20th century cannot be considered fully "paradigmatic"; instead, they are artisanal, customized, individual, rather than large-scale). In addition, the phenomenon of multi-apartment housing itself is relatively recent – it is hardly appropriate to track it in Russian cities before the post-revolutionary or pre-industrial period. The monolithic cycle cannot be clearly seen due to the fact that the total "experience" of its deployment so far, even in the most advanced cities, such as Yekaterinburg, does not exceed two decades.

We recognize the distinct nature of the K4 panel cycle and the more diffuse character of K3 and K5. (As for the K1 and K2 cycles, they are studied worldwide at the country level, rather than at the regional or urban level or at the level of individual enterprises, because in the 18th–19th centuries, in most countries going through industrialization, there were no established and archived statistics on enterprises and cities, though the data aggregated at the country level are available to a modern researcher.)

The second line of criticism is that the authors underestimate the role of individual residential construction in the long-term data series on the delivery of multi-apartment housing in Russian cities. According to the Institute for Urban Economics[10], three categories of the prevalence of individual housing construction can be distinguished by the proportion of the total residential area in individual residential buildings in the total volume of housing stock: significant (25–50%), middle (15–20%) and insignificant (<15%).

Most of the cities in our sample: Omsk, Novosibirsk, Nizhny Novgorod, Chelyabinsk, Khabarovsk, Samara, Voronezh, Perm, Yekaterinburg, Vladivostok, Irkutsk, Krasnoyarsk, Arkhangelsk, Murmansk – fall into the latter group: from 11% in Omsk to 0.3% in Murmansk, respectively. At the same time, of course, if we are talking about the share of individual residential construction in these cities in the last two decades, it will be higher (2-fold in some cities, for example, in Tyumen, which belongs to the second group, according to our estimates) due to the activation of individual residential construction after 1995.

Tyumen alone falls into the middle group of our sample. Its share of individual residential construction in the entire stock is 17%, and the share of individual residential construction in annual housing delivery can reach up to a third of the total in some years. But since this share fluctuates from year to year, it is difficult to take into account its role and, as a result, adjust our conclusions for Tyumen. Let us say in general that the increasing variety of stories and materials of residential buildings corresponds to the spirit of the monolithic cycle and that the word "monolithic" means only its dominance, but does not exclude all other types of residential buildings that appear simultaneously with monolithic houses.

The share of individual residential construction is significant in three cities of our

[10] The authors thank their colleagues from the Institute for Urban Economics for providing data on individual housing construction.

sample: 33% in Volgograd, 26% in Krasnodar and Rostov-on-Don (in the total housing stock of the city). It is likely that this share is higher in the annual dynamics of recent years. But due to the fact that we did not have data on the delivery of individual residential construction in every year of the 21st century, it is difficult to say more definitely. Summarizing the situation, it can be noted that the three given cities, upon closer examination, should be separated into a separate "production" for a thorough analysis of the realities and drivers of the technological evolution of residential housing in the last two decades, the period of the monolithic cycle.

The third line of criticism was the argument that there are not enough cities in our sample (only 2 out of 42, i.e. less than 5%) with a population of 250–500 thousand people and that it is advisable to increase their number and share in the analysis significantly in order to be able to compare the results according to the patterns of long-term technological evolution between three groups of cities of different sizes (the increase in the number of cities with a population of 500 thousand – one million people is also desirable). We recognize this proposal as a task for future work.

Conclusion

To sum up, each "Kondratiev" (Kondratiev's half-century cycle) created its own peak in the total area of multi-apartment buildings in the city. This peak was provided by the massive use of new technologies and construction materials and, in the canonical case, was higher than the previous one. These peaks were separated from each other by a distance of 40–60 years and diagnose the effects of a radical change in technology.

The transition to the new Kondratiev in the construction of multi-apartment buildings was often accompanied by a geographical shift of the cities leading in the technological structure: Murmansk – Arkhangelsk, Rostov-on-Don – Krasnodar, Nizhny Novgorod – Samara. The effects of incremental technological innovations (modification of materials, structures, construction methods, etc.) were often (but not always, because this trend has slowed down in recent years) accompanied by an increase in the average size of the total area of multi-apartment buildings in brick, panel, and previously wooden housing.

The effects of path dependence manifested themselves in the long-term inertial preservation of girder foundations in the construction of multi-apartment buildings in Murmansk, Irkutsk, and Samara, which became a brake on the mass transition of cities to multi-story buildings and new technologies of monolithic housing construction (K5). The preserved strong traditions of wooden house building, ceteris paribus, on the contrary, created conditions for shortening the next panel cycle (delaying its rooting) and favorable prerequisites for an earlier transition of the city to monolithic house building technologies (K5).

The initial hypothesis that technological innovations in the construction of multi-apartment buildings in Siberian cities have "diffused" from west to east has not been confirmed by empirical testing (comparative analysis of Omsk – Tyumen – Novosibirsk – Krasnoyarsk – Irkutsk). The hypothesis of Vladivostok's initial advantage over Khabarovsk during the transition from K4 to K5 was also not confirmed, and the technological development of both cities turned out to be similar.

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