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Challenges of Modernizing Standardized Residential Buildings: The Case of A1-451 KP Series in Armenia

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Abstract. This study examines the modernization challenges of standardized residential buildings in Armenia, focusing on the widely used A1-451 KP (А1-451 КП) series as a representative case. The objective is to identify feasible modernization strategies by analyzing relevant international experiences and evaluating their applicability to the Armenian context. The article employs methods such as the collection and synthesis of archival materials and technical documents, systemic and situational analyses, and the review of government decisions and legal acts related to housing policy. The results reveal that A1-451 KP buildings suffer from significant physical deterioration, outdated infrastructure, and seismic vulnerability, compounded by insufficient institutional and legal mechanisms for renovation. Special emphasis is placed on interdisciplinary collaboration, which is considered essential for developing comprehensive and sustainable modernization solutions. The findings support the urgent need for a multi-level strategy to modernize not only the A1-451 KP series but also Armenia's entire stock of standardized residential buildings, ensuring structural safety, improved living conditions, and resilience against seismic risks.

Introduction

In Armenia, buildings of the A1-451 KP (А1-451 КП) series were constructed during the Soviet Union as part of mass housing programs. Over time, these buildings have lost their technical reliability, and their modernization has become an urgent task. The article aims to present the main challenges of modernization and possible ways to overcome them, based on both local and international experience. The article also emphasizes the importance of interdisciplinary collaboration as a prerequisite for developing effective solutions. The study focuses through interdisciplinary cooperation on analyzing the architectural-structural, engineering, and other problems of standard-design residential buildings. Particular attention is paid to international experience, from which lessons are synthesized for Armenia. The selection of literary sources was based on the review and collation of both local and international studies relevant to the topic. Several key directions were identified in the process of literature selection, including: local scientific studies addressing the problems and potential solutions for the modernization of residential buildings [1, 2, 4, 13, 14, 15, 16, 17, 18, 19, 34, 38]; research focused on the seismic risk assessment of Yerevan [4, 5, 6, 7, 8, 9, 10]; construction norms and regulatory documents of the Republic of Armenia [11,12]; international experience in the modernization of residential buildings, including scientific books [21,24] and journal articles [3, 20, 22, 23, 25, 26, 27, 28, 29, 30, 35, 36, 37, 39, 40]; scientific works highlighting the importance of interdisciplinary collaboration [31, 32, 33]; and studies dedicated to the methodological approaches to residential building modernization [41, 42, 43, 44]. The A1-451

KP series is examined separately as a widely distributed stock, as an example, the analysis of buildings designed in this series can be applicable to the study of other standard-design residential buildings. The article seeks to respond to the necessity of modernization, and the conducted research allows the conclusion to substantiate the sequence of steps directed toward the modernization of standard-design residential buildings within the organization of the process. The scientific novelty of the study lies in the systematization of international experience and local analyses into a unified approach for the modernization of standard-design residential buildings, demonstrated through the case of the A1-451 KP series.

Materials and Methods

The work was developed on the basis of a study of published and archival sources on international and Armenian experience, archival and current documents (scientific articles, reports, legal acts, regulations), records of realized and unrealized projects, and original research data, using scientific methods of analysis and generalization. These methods were applied to identify the key structural, seismic, and energy-efficiency problems of A1-451 KP series buildings and to evaluate possible modernization directions based on both local conditions and international experience.

1. Overview of Yerevan's housing stock and standard-design residential buildings

Standard-design residential construction in Armenia began to develop in the 1950s, against the backdrop of a widespread housing crisis across the Soviet Union. During these years, mass housing construction was launched, largely based on pre-developed standard projects. This phenomenon was not unique to Armenia but occurred in various countries worldwide, shaped by the legacy of the 19th-century industrial housing period and the post-World War II economic recovery. In the Soviet Union, the main driver was the acute housing shortage, and by the 1950s residential construction aimed to provide dwellings rapidly and at minimal cost [1]. In the initial stage in Armenia, five-story buildings constructed with stone and monolithic structures were widely applied, not only in Yerevan but also in other Armenian cities. However, from the second half of the 1960s, large-panel and frame-and-panel multi-apartment buildings became predominant in housing construction. In this phase, projects such as A1-451 KP, 111, and 129 were introduced. These standard projects were designed by "Armprojec" institute. Some of the original technical passports of these buildings are preserved in the archives of the "Armproject" Institute. The majority were designed as 4 to 9-storey buildings. Very few series standard-design residential buildings was developed in Soviet state design institutes and were frequently transferred directly to the republics without sufficient adaptation to local conditions, importantly, these projects were rarely adjusted to Armenia's seismic, climatic, or architectural characteristics, which in turn led to functional and technical problems in residential quarters built in Yerevan [1].

As in many other countries, in Armenia the system of standard-design and prefabricated residential construction began to decline in the 1980s and 1990s. The reasons were different across contexts: in a number of European countries the decline was linked to decreased demand caused by rapid physical and moral deterioration of the buildings (poor living conditions, "lack of individuality," etc.) [2, 3], while in Armenia the collapse of industrial construction after the dissolution of the USSR was the main cause. The devastating Spitak earthquake of 1988 further exposed the insufficient seismic resistance of many standard-design buildings, and as a result, the construction of several series was prohibited. At the same time, some other series, after undergoing review, continued to be built, including the A1-451 KP series. Despite the subsequent reduction in construction, these buildings

remain a vast heritage, continuing to play a central role in Armenia's, and especially Yerevan's, housing stock, making their future a matter of national importance.

If we attempt to roughly distinguish phases in the development of residential construction in Armenia, the picture may be summarized as follows: beginning in the second half of the 1950s, serial standard-design housing construction was introduced, at first mainly in the form of stone buildings with load-bearing masonry walls and precast reinforced-concrete floor slabs. In the following stage, mass construction expanded with different types of standard-design buildings, including large-panel, frame-and-panel, and braced-frame systems, as well as buildings using lift-slab construction methods with increased number of stories. After 1991, however, the majority of new residential buildings were constructed according to individual designs, predominantly as reinforced-concrete monolithic structures. According to 2021 data, more than 85% of Yerevan's housing stock consists of residential buildings constructed between the 1950s and the 1980s. Following the changes in national construction standards from 1989 onward, new requirements were introduced, and many previously used series, notably 129 and 111, were no longer considered adequate from a safety perspective. Since then, the construction of standard-design multi-apartment buildings in Armenia sharply decreased, gradually giving way to housing construction based on individual projects.

The modernization of standard-design residential buildings cannot be addressed without considering their structural characteristics. Given the scale of housing construction in the Soviet period, it is necessary to classify the buildings according to structural systems and other defining attributes [4]. In Yerevan, the most frequently encountered structural systems are: stone and composite buildings up to 5 stories, large-panel buildings up to 9 stories, frame-and-panel buildings up to 9 stories, buildings constructed by the lift-slab method up to 16 stories, frame and braced-frame buildings up to 16 stories. In parallel, standard-design buildings may also be classified by their series. The most widespread series in Yerevan include: 111, 112-111, 122-111, 129, A1-451 KP, 1-451 P, and 1A-450. There are also numerous buildings constructed in the city whose series names and technical passports have not yet been identified.

Seismic Risk in Yerevan. The territory of the Republic of Armenia is classified among the most seismically active regions of the world. Historical and statistical records demonstrate that numerous high-energy earthquakes have been documented in the region. Analyses indicate the possibility of seismic events with a magnitude ≥7.0, with a recurrence interval of strong earthquakes of approximately 30-40 years.

A significant portion of buildings constructed in Armenia during the Soviet period were designed for a seismic intensity level of 7-8 according to MSK-64, which proved insufficient in the face of the 1988 Spitak earthquake [5]. The earthquake of December 7, 1988, with a magnitude of 6.8-6.9, reached intensities of 9-10 in the epicentral area, particularly in Spitak and nearby regions, substantially exceeding the established design parameters [5, 6]. This discrepancy exposed critical structural vulnerabilities in many buildings. According to official estimates, approximately 25,000 people died and over 500,000 were left homeless as a result of the disaster [5]. The event affected multiple towns and villages in northern Armenia, revealing the necessity of revised seismic hazard assessment and updated building regulations [6, 7].

NZNSEE (1993) presents a post-event field report on the 7 December 1988 Spitak earthquake. The report summarizes the seismotectonic setting, the available strong motion records, and observations of building performance in the affected cities, including Leninakan. It documents extensive damage

and collapses in precast residential systems and notes that local ground and the 300-400 m-deep sedimentary basin conditions contributed to amplification of shaking [8].
After reviewing several studies conducted on this topic [6, 9, 10], it can be concluded that the consequences of the earthquake were caused by multiple factors, including:

1) underestimation of seismic hazard
2) violations of design norms,
3) poor technical quality of construction,
4) high-energy vertical components of seismic waves,
5) incomplete implementation of seismic design codes,
6) insufficient awareness and preparedness of the population in emergency situations.

Since 1989, systemic reforms have been undertaken to improve seismic safety. In particular:

- the seismic hazard level of Armenia was reassessed,
- a new seismic zoning map was developed,
- and national design norms were elaborated in accordance with updated scientific and technical requirements.

In 1995, the national code RABC II-2.02-94 "Seismic Resistant Construction: Design Norms" was introduced, and in 2006 it was revised as RABC II-6.02-2006, incorporating international experience and providing a more accurate representation of local seismic risks [11]. The revised norms introduced a new seismic zoning system, dividing Armenia into three zones with gradually increasing seismic impact. The most recent code, RABC 20.04-2020 (adopted on 28 December 2020), defined new maximum expected horizontal accelerations for seismic zones: 0.3g (Zone 1), 0.4g (Zone 2), and 0.5g (Zone 3), compared with the previous values of 0.2g, 0.3g, and 0.4g. According to these regulations, the design basis now requires earthquake resistance corresponding to ≥9 on the MSK-64 scale [12].

These developments are aimed at ensuring higher seismic resilience of construction, reducing human and material losses, and enhancing the overall resistance of Armenia's building stock to potential future disasters.

Overview of energy efficiency in Armenian residential buildings. Since the majority of Armenia's multi-apartment residential buildings are 35-60 years old, and the construction of these buildings did not comply with current energy-efficiency standards, according to various expert calculations the specific energy consumption per 1 m² in such buildings exceeds that of developed countries by approximately 30-50%. This is primarily the result of the poor thermal performance of the building envelope. According to a 2019 study, about 70% of Armenia's building envelopes are constructed of stone, while 23% are made of panels (Fig. 1).

According to the Cadastre Committee, the total housing stock of the Republic amounted to 100.2 million m² at the end of 2021, including 55.9 million m² in urban areas and 44.3 million m² in rural areas. Below is the distribution of building envelopes in Armenia.

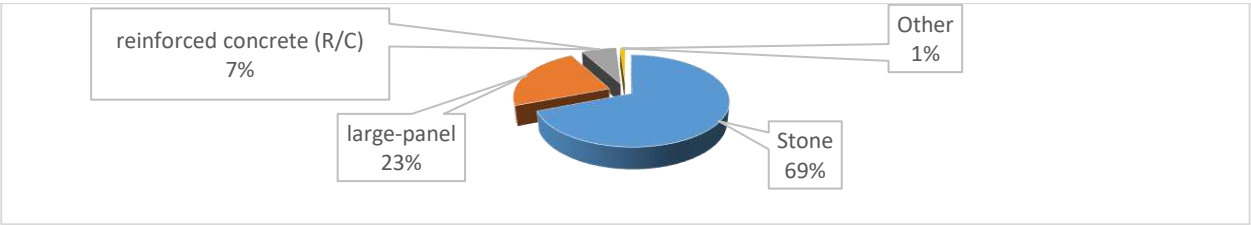


Fig. 1. Percentage distribution of multi-apartment buildings by exterior wall material.

In the climatic zone of Yerevan, under design calculation conditions, a condensation zone forms within the building envelope. This phenomenon depends significantly on the calculated outdoor air temperature and consequently on the vapor elasticity coefficient. As a result, in the building envelopes located in this climatic zone, a condensation zone develops, which causes structural degradation. If the condensation zone approaches the metal components embedded in the structure, the bond between metal and concrete may be lost, leading to a weakening of the structure, an undesirable or even unacceptable outcome. This issue can be avoided by applying external thermal insulation on the building envelope.

Scientific studies on standard-design residential buildings built in Armenia. There are a number of studies and programs concerning the A1-451 KP series buildings as well as other standard-design residential buildings. These works mostly focus on modernization from specific perspectives, for example, issues of architectural appearance, energy efficiency, or seismic resistance. Among such publications:
Melkumyan (2020) presents the retrofit design for a damaged 9-storey large-panel apartment building in Stepanakert (built 1988), using basement-level base isolation combined with 80 mm R/C jackets to strengthen first-floor load-bearing walls, the author notes this would be the first application of base-isolation retrofitting to a building with an R/C large-panel bearing system, and that the concept enables retrofit without interrupting use and at ~5× lower cost than conventional strengthening [13]. Beyond this article, Melkumyan has published numerous works and implemented projects using this modernization method.

Hakobyan (2014) examines modernization of standardized large-panel housing with attention to both energy-efficient envelope retrofits and facade architectural strategies, while Papoyan (2021) focuses on building-energy performance modeling and PV sizing. Read together, the two studies underscore the importance of modernizing Soviet-type residential blocks, with energy efficiency emphasized across both, and facade renewal specifically addressed in Hakobyan (2014) [14,15].

In their study, Palyan and Avagyan (2020) present an approximate seismic-risk assessment for six districts of Yerevan's Avan community, calibrated to the Spitak-earthquake experience. By tallying local building types (notably the 111 frame-panel and A1-451 KP large-panel series) and resident counts, they identify districts with relatively higher and lower risk. The study also provides district-level risk signals and series-specific context, including the reported strong performance of 9-storey A1-451 KP-1c/1 buildings under intensity-9 shaking, which can inform priorities for modernization and strengthening [16].

Galstyan, Arzumanyan, and Galoyan (2020) compare two residential buildings erected by the same firm, an A1-451 KP-1n/9 large-panel building (2008) and a monolithic reinforced-concrete wall building (2014), both designed to the same Armenian seismic code, and find that, on a per-square meter basis, the large-panel variant was 33.6% less expensive and was built faster (6 months vs. 24

months). This supports their conclusion that modernized large-panel house-building has clear techno-economic advantages under local conditions [17].

Borushkina & Sapunova (2023) compare socialist-era mass housing in Moldova, Armenia, and Uzbekistan as "utilitarian heritage", arguing that renewal prospects are limited less by technical factors than by cultural, historical, and socio-economic constraints. They also note that post-Soviet "super-homeownership" (~90% private share) and the continuing dominance of Soviet-era estates shift the burden to owners for maintenance, infrastructure renewal, and energy-efficiency upgrades, context directly relevant to how modernization policies can be designed [18].

Besides these articles, the works by Azatyan and co-authors provide more general analyses aimed at identifying modernization problems [1, 2, 4, 19]. In one of the papers, the authors note that, for Yerevan, research has mostly focused on techno-economic solutions, creating the impression that the main problem lies precisely there, they argue this is a serious gap [4]. Building on this, they conclude that the root problem is one of governance, unclear responsibilities, weak coordination, and insufficient state-level mechanisms, rather than technical measures alone [4]. The paper also reviews modernization visions proposed by other authors and the Territorial Service of Seismic Protection, alongside other issues in the modernization process of Standard-Design Residential Buildings [4].

All of these studies address critical issues in the process of residential building modernization, however, what is still lacking is a unified modernization methodology that can be applied across different types of buildings. More broadly, the article sets out general approaches so that modernization mechanisms function as a whole, rather than focusing on energy efficiency while neglecting structural or architectural problems. The process should involve specialists from different fields, and we propose general principles for modernization programs. It is also necessary to take into account issues of governance and financing. Modernization programs must include the participation of lawyers and economists, who can prepare the financial calculations so that the responsible institutions, whether state, private sector, or joint entities, understand the costs, timelines, and resources required.

2. International experience review: considerations for Armenia

Internationally, modernization programs for standard-design residential buildings have evolved along technical, social, and political dimensions. Successful cases typically use an integrated approach that combines architectural, structural, energy-efficiency, financial, and participatory solutions. Moreover, in several countries these processes have been guided by clear methodological models that can inform Armenia's path. The following analyses of modernization examples from Poland, Germany, and Russia outline lessons that may be adapted for Armenia.

Poland: Modernization of housing estates. In Poland, large-panel housing estates (blokowiska) built after World War II accommodate around 12 million people, more than 30% of the population, and remain a key part of the urban housing stock [20]. Despite their role in solving post-war housing shortages, these estates soon revealed serious shortcomings, including poor insulation, outdated installations, weak social cohesion, and rapid physical wear due to low-cost prefabrication methods [20, 21, 22]. Their technical lifespan is estimated at 100 years, but functional and aesthetic obsolescence appears after about 60 years, making modernization essential [20].

Modernization programs have focused on three main directions: thermal retrofitting (insulation of walls and roofs, window and facade replacement), functional upgrades (improvements of apartment

layouts, adaptations for disabled residents, new balconies/loggias), and urban improvements (better green spaces, parking, and local services) [20]. Large-scale demolition is not considered realistic due to persistent housing shortages, so comprehensive renovation and thermo-modernization remain the dominant strategy [20, 21]. From a policy perspective, mass privatization in the 1990s transferred ownership of over 80% of flats to private residents [23]. According to the 1995 Housing Act, homeowner majorities can form "Housing Commonwealths" responsible for collective management [21]. However, fragmented ownership has complicated financing and delayed repairs [22]. Additional models such as TBS (Social Housing Associations) emerged, combining preferential loans, municipal land, and tenant contributions [21]. Scholars emphasize that modernization must combine energy efficiency, functionality, aesthetics, and stronger institutional frameworks to overcome ownership fragmentation [21, 23, 24]. While Poland continues to debate the "future of the blokowisko," it is generally recognized that these estates remain indispensable for millions, requiring systematic investment and innovative governance solutions [21, 23].

Overall, Poland's experience shows that, given the estates' scale and continuing housing need, comprehensive thermo-modernization with functional and urban upgrades, backed by stronger condominium governance and financing tools, offers a more viable path than large-scale demolition.

Germany: Modernization of housing estates. In Germany, the modernization of large-panel housing estates evolved through programs such as Soziale Stadt (1998) for socially integrated neighborhood management and Stadtumbau Ost (2000) for controlled shrinkage and urban quality [21]. In the former GDR, "Rekonstruktion" had already meant standardized, industrialized repair and upgrading of existing stock, a path that continued after reunification [3].
Under Stadtumbau Ost, municipalities and housing companies combined urban restructuring, partial demolition to reduce density, diversification of housing layouts, new services, parking, and green areas, with comprehensive refurbishment measures such as insulation, updated plumbing, balconies, and improved facades [20]. Demolished panel elements were often recycled or reused in smaller houses, linking shrinkage to circular construction [20]. Cooperative and rental ownership structures facilitated tenant relocation during these processes, in contrast to much of the post-socialist region where mass privatization left fragmented ownership and weak collective responsibility [22].

In the German context, recent literature emphasizes prefabricated retrofit modules for facades and roofs, enabling rapid modernization with minimal eviction and reported energy savings of up to 80%, while also accommodating balcony and attic extensions [25]. Beyond technical solutions, Germany's tenant culture and rent protection have tempered segregation, while governance reforms and partial privatizations have shaped divergent trajectories in estate management [24].

Overall, Germany's experience illustrates a dual-track approach: selective demolition and urban restructuring in depopulated areas of the East, and comprehensive refurbishment where occupancy remained stable. Both were embedded within nationally supported frameworks (Soziale Stadt, Stadtumbau), highlighting the importance of integrated policy, tenant protection, and industrialized retrofit methods in sustaining large-panel estates [20, 21, 24].

Russia: Modernization of housing estates. Soviet-era mass housing continues to constitute the core of Russia's urban stock. Following large-scale privatization, homeownership rates reached over 90%, creating a system of "super-homeownership" without strong mechanisms for managing common property [22]. As a result, owner associations often lack capacity, and uncoordinated, apartment-level repairs have produced fragmented facades and uneven quality, illustrating how privatization

complicated estate-level modernization. Since the 2000s, infill construction in micro-districts has reduced green areas and strained infrastructure, leading to public dissatisfaction. In response, the federal "Comfortable Urban Environment" program (2017) has emphasized public-space upgrades, though it has been criticized for top-down decision-making and limited citizen participation [26].
The most significant initiative has been Moscow's 2017-2032 Renovation Program, targeting outdated five-story stock through demolition and rebuilding, densification, and estate-level renewal. This program combines area-wide redevelopment, new high-rise construction, reprogrammed public spaces, upgraded streetscapes, with building-level improvements, while raising debates over financing, implementation, and residents' rights [27, 28]. At the technical level, modernization practices for standard panel series typically include re-sealing inter-panel joints, improving ventilation, adding external insulation systems (EPS/mineral wool), strengthening roofs, and repairing balconies. Internal insulation is possible but less effective due to moisture risks [29].

Overall, Russian experience highlights the tension between large-scale redevelopment and localized modernization. Weak coordination between housing policy and urban planning, coupled with fragmented ownership, continues to hinder integrated approaches and the efficient balancing of technical renewal with social needs [30].

Comparative analysis for Armenia. The experience of different countries shows that the modernization of mass housing estates requires not only technical interventions but also alignment with organizational, financial, and socio-political frameworks. The Russian and German cases are particularly valuable in terms of integrated approaches: both demolition and new construction (renovation) as well as comprehensive refurbishment (capital repair) strategies are applied, depending on the building's condition and urban development priorities, alongside partial modernization measures in specific directions (such as thermal insulation, facade improvements, and upgrades of common-use areas). In Poland, however, large-scale demolition and rebuilding are not considered realistic; thermal modernization is seen as the only feasible strategy.
In Armenia, particularly in Yerevan, the presence of the same panel series and the high seismic vulnerability underline the need for such a systemic approach. Taking into account the country's specific conditions, a modernization program should: consider the local level of seismic risks, be implemented through phased, targeted programming based on detailed assessment, with the application of new technologies, waste reuse, and other cost-reducing measures, provide a legal framework for strengthening homeowners' associations and resident participation, ensuring responsibility for the use, maintenance, and improvement of common property, and encourage co-financing schemes between the state, municipalities, and private actors, as well as the involvement of investors.

On the basis of effective pilot projects, it will be possible to scale up broader actions by combining local experience with the methodological and organizational models that have proven successful in other countries.

Interdisciplinary collaboration for residential modernization. Coordination in AEC requires integrating multiple disciplines so that components function cohesively, early, interactive participation by architects, engineers, and clients improves quality, timelines, and budgets [31]. A challenge is that many projects operate in mixed 2D CAD and 3D BIM environments, while most studies assume "all-BIM." To address this, a dual-level Open BIM framework, single-discipline collaboration in mixed 2D/BIM plus multi-discipline integration in 3D BIM, has been proposed, using standards such as IFC/BCF/bsDD to manage data exchange [31].

For housing modernization, rigorous pre-renovation diagnostics are essential. One study introduced a large-scale assessment of residential facades that categorizes renovation intensity (A-D) across service life, thermal performance, degradation, and aesthetics. The interdisciplinary method (machine learning + big data) achieved >95% accuracy and reduced evaluation time from weeks to hours, supporting design decisions [32]. Overall, these sources highlight the need for multi-disciplinary integration with clear data-exchange standards [31], the use of virtual/immersive collaboration for early teamwork [33], and data-assisted diagnostics that align renovation intensity with measured performance, linking assessment directly to design decisions [31, 32, 33].

In this study, we operationalize an interdisciplinary approach, bringing together architects, structural engineers, and mechanical and energy engineers, to jointly diagnose the characteristic problems of standardized residential blocks and co-produce a set of generic modernization pathways and solutions. In subsequent modernization phases, coordinated input should also be integrated from planning and management professionals, as well as economists, technical auditors, and cost estimators.

3. Description and distribution of A1-451 KP series buildings in Yerevan

When discussing the modernization of standard-design residential buildings, it is essential to identify the specific design series, analyze the structural systems of the buildings, assess their conformity with contemporary regulatory requirements, and review energy-efficiency performance, among other aspects. Moreover, to analyze architectural issues, the architectural environment and common-use spaces, each neighborhood and each building must be examined individually. In this study, the focus is placed on standard-design residential buildings of the A1-451 KP series. In Yerevan, A1-451 KP series buildings are found in nearly all administrative districts. They occur with higher density in Malatia-Sebastia, Avan, Kanaker-Zeytun, Davtashen and Nor-Nork.

The majority of standard-design residential buildings were designed by the “Armproject” design institute. The design passport of the A1-451 KP buildings is preserved in the archives of “Armproject”, however, not all design passports of standard-design residential buildings have been preserved. This hinders the comprehensive collection of precise data on series prevalence and exact counts. In this article, A1-451 KP residential buildings are considered as a representative example, they were constructed not only in Yerevan but also in various cities of Armenia. Nevertheless, the analysis here includes only those located in the capital. These buildings appear in almost all administrative districts of Yerevan, and this section presents a classified list by administrative division.

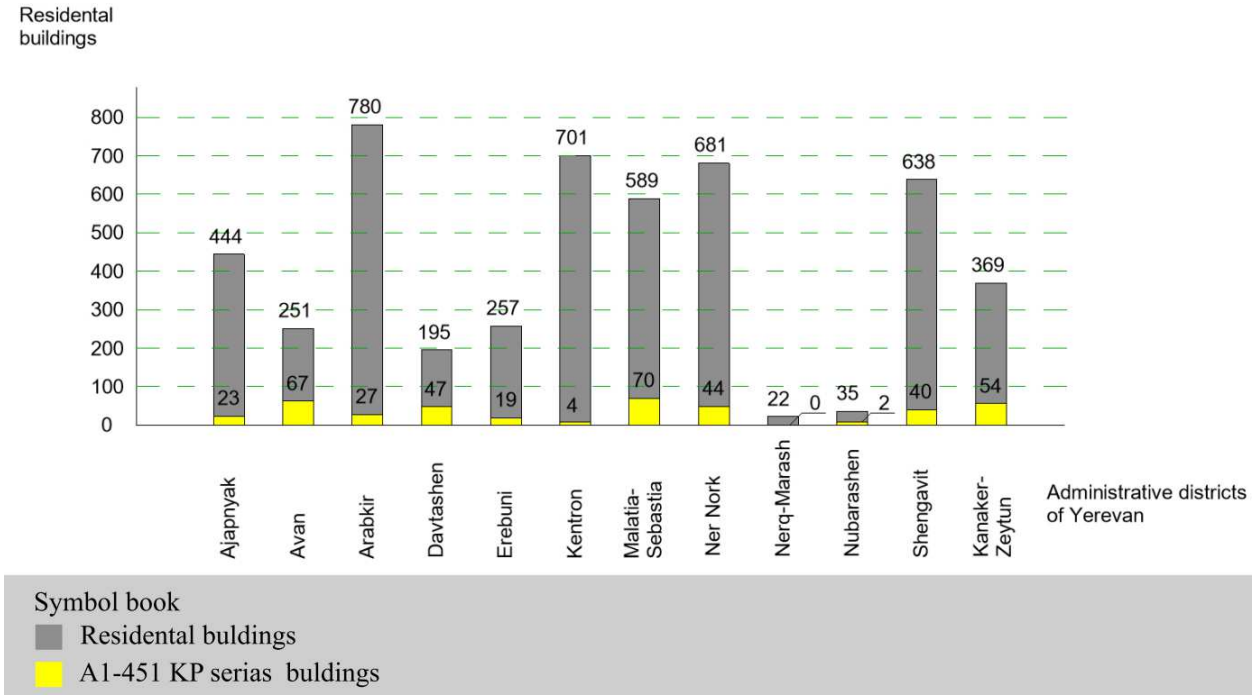


Fig. 2. Number of A1-451 KP series buildings by administrative district of Yerevan (based on field-survey results), the figure also indicates the total number of existing residential buildings by district, with baseline data drawn from the official website of the Yerevan Municipality.

Analysis of structural systems in A1-451 KP series buildings. The structural solutions of A1-451 KP series large-panel residential buildings, widespread in several Armenian cities, particularly Spitak, Gyumri, Yerevan, and Vanadzor, do not comply with current regulatory requirements. These buildings were designed under Soviet-era seismic-resistance standards, which were based primarily on 6-7 intensity levels, without accounting for the probability of stronger earthquakes in the region. The A1-451 KP buildings do not conform to the current RABC 20.04-2020 standards, as they were originally designed in accordance with the earlier RABC II-2.02-94 seismic design code. Moreover, this series of buildings does not ensure adequate protection of life and health under seismic impacts of ≥9 intensity, which highlights the necessity of structural strengthening or phased reconstruction. Studies based on the experience of the Spitak earthquake have shown that the seismic resistance of A1-451 KP buildings varies depending on local soil conditions. For example, according to Palyan and Avagyan (2020), in several districts of Yerevan's Avan district, the probability of damage to such buildings ranges from 0% to 65% [16]. Therefore, comprehensive strengthening measures must be implemented.

Recommendations

For the structural strengthening of A1-451 KP series buildings, the following measures are recommended for consideration, among others:

- reinforcement of foundations (e.g., with FRP composites),
- creation of rigid horizontal diaphragms,
- and redesign of joint areas to meet ductility requirements.

Furthermore, considering the age of these buildings and the factor of material degradation, in some cases it may be more efficient and economically justified to pursue phased demolition and replacement with modern seismic-resistant designs.

Analysis of technical characteristics and energy-efficiency systems in A1-451 KP series buildings. The A1-451 KP series buildings have a rectangular configuration with corner-protruding balconies. The building also includes a basement floor with a height of 2.5 meters, while the standard floor height is 3 meters. It is a large-panel structure composed of prefabricated reinforced-concrete panels with a thickness of 30 cm. The intermediate, roof, and basement slabs are made of multi-hollow reinforced-concrete panels. The staircases are constructed from prefabricated reinforced-concrete elements.
There are some main technical indicators from the original technical passport.

Construction volume – 9907 m³
Including above-ground part – 7050 m³
Building footprint – 407.58 m²
Total floor area – 4253.3 m²
Living area – 2073.10 m²
Auxiliary (non-living) area – 1759.10 m²

Structural characteristics. The structural system consists of transverse and longitudinal load-bearing axes with beam supports on slab coverings. The wings include a continuous solid corridor.
Foundations – reinforced-concrete strip foundations (monolithic).
Floor slabs – large-panel, multi-hollow reinforced-concrete slabs, 22 cm thick, with longitudinal reinforcement; production plant No. 4.
External walls – large-panel reinforced-concrete, 30 cm thick.
Internal walls – gypsum-concrete hollow panels, 10 cm thick; production plant No. 10.
Internal structural walls – gypsum-concrete hollow panels, 25 cm thick.
Sanitary units – prefabricated reinforced-concrete cabins; plant No. 4.
Staircases – prefabricated reinforced-concrete flights and landings; plant No. 2.
Elevator shafts – prefabricated reinforced-concrete panels; plant No. 3.
Roof structure – ribbed reinforced-concrete panels with internal drainage; plant No. 4.
Roofing – non-roll, flat type.
Thermal insulation – made of mineral-binder composite material (laminated panel), total mass 5.26 t.

Engineering systems. Water supply – domestic and potable, with a design head of 35 m at the base of risers.
Hot-water supply – from the external network, with a design head of 35 m at the base of risers.
Sewerage – domestic and fecal, connected to the municipal network, internal drainage.
Heating – central, hot-water, one-pipe system with top distribution, cast-iron radiators, natural circulation.
Design coolant temperature: 95-70 °C.
Gas supply – household network, with 2, 3, or 4-burner gas stoves in kitchens (8.9 m²).
Electrical supply – 220/380 V lighting and power circuits.
Telecommunication – telephone and radio networks provided.
Elevator – passenger and freight type, load capacity 320 kg.
Garbage chute – located on each floor, equipped with a removable container.

Additional data. The gas pipelines are designed for construction in seismic regions, at a design temperature of -21 °C and seismicity of 8 points, with a foundation depth of 1.8 m. The external wall panels are designed for a load of 630 kg/m². The project was developed in two variants, with

and without an elevator. Year of design: 1969

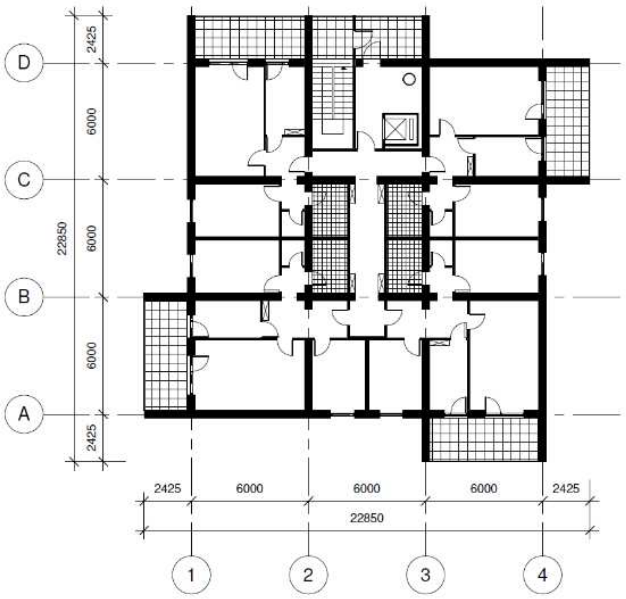
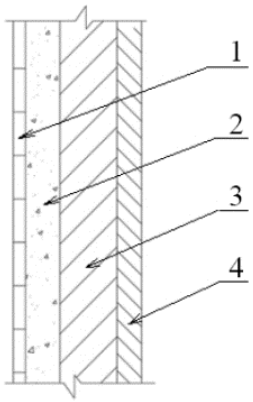


Fig. 3. Typical floor plan of an A1-451 KP series building.

Considering the absence of sufficient thermal insulation in the original design of A1-451 KP series buildings, the following section analyzes their energy-efficiency characteristics. Presented below are the exterior wall assemblies of A1-451 KP series buildings (configurations that are also common in other standard-design residential buildings of 9, 14, and 16 stories), together with their thermal-engineering calculations.



1. Arctic tuff, $\delta_1 = 0.02m, \lambda_1 = 0.52$ Wt/m ^{0}C,
2. Concrete filling, $\delta_2 = 0.1$m, $\lambda_2 = 0.76$ Wt/m ^{0}C ,
3. Reinforced concrete panel, $\delta_3 = 0.16$m, $\lambda_3 = 1.92$ Wt/m ^{0}C ,
4. Gypsum plaster, $\delta_4 = 0.02$m, $\lambda_4 = 0.41$ Wt/m ^{0}C ,

Fig. 4. Exterior wall assemblies of A1-451 KP series buildings.

According to Fig. 4, the calculation of the thermal resistance and heat transfer coefficient was carried out for the cladding structure:

$$R_0 = \frac{1}{\alpha_{in}} + R_s + \frac{1}{\alpha_{out}}, \quad (1)$$

Where: α_{out}- is the thermal conductivity coefficient of the external surface of the structure, W/m^2 ^{0}C

α_{in}- is the thermal conductivity of the internal surface of the structure, W/m^2 ^{0}C

R_s- is the thermal resistance of the enclosing structure, m^2 ^{0}C/W

$$R_s = \frac{\delta_1}{\lambda_1} + \frac{\delta_1}{\lambda_2} + \cdots + \frac{\delta_n}{\lambda_n} \quad (2)$$

Where: λ_n- is the calculated value of the thermal conductivity coefficient of the layer material, W/m^{0}C

δ_n- layer thickness, m

$$R_s = \frac{1}{23} + \frac{0.02}{0.52} + \frac{0.1}{0.76} + \frac{0.16}{1.92} + \frac{0.02}{0.41} + \frac{1}{8.7} = 0.46 \text{ m}^2\,^0\text{C/W}, \quad (3)$$

$$k_s = \frac{1}{0.46} = 2.17 \text{ W/m}^2\,^0\text{C} \quad (4)$$

Recommendations. Table 1 presents recommended minimum insulation thicknesses for future applications in Yerevan, namely, expanded polystyrene (EPS), extruded polystyrene (XPS), and mineral wool. The values are calculated for exterior walls with a 300 mm reinforced-concrete (RC) panel and a degree-day total of 2755, targeting a wall thermal resistance of R_{wl} = 2.50 m²·°C/Wt. Under these conditions, the minimum continuous insulation layers are 0.09 m (EPS), 0.07 m (XPS), and 0.08 m (mineral wool). These figures are guidance values intended to support retrofit and design decisions and should be verified at project level using the applicable material properties and calculation method [34].

Table 1. Recommended minimum thicknesses of thermal insulation materials for Yerevan.

The minimum thickness of the thermal insulation layer of a wall with a 300 mm thick RC panel structure:

City	The degree day D_{day},	R_{wl}, m²·°C /Wt	Polystyrene Expanded (EPS), m	Extruded Polystyrene (XPS), m	Mineral wool, m
Yerevan	2755	2.50	0.09	0.07	0.08

Architectural environment analysis of residential districts built with A1-451 KP series buildings. For the modernization of each standard-design residential building, a precise, location-specific analysis must be conducted. For this reason, the 8th block of the Nor Nork administrative district, developed with A1-451 KP series buildings, was selected as a case study.

The buildings in this area do not differ from the general design features of the series, however, their spatial organization, physical condition, and socio-urban environment present a number of specific characteristics. For a more detailed investigation, the residential quarter located between Davit Bek, Hunan Avetisyan, and Karakhanyan Streets, composed of A1-451 KP large-panel buildings, was examined (Fig. 5).

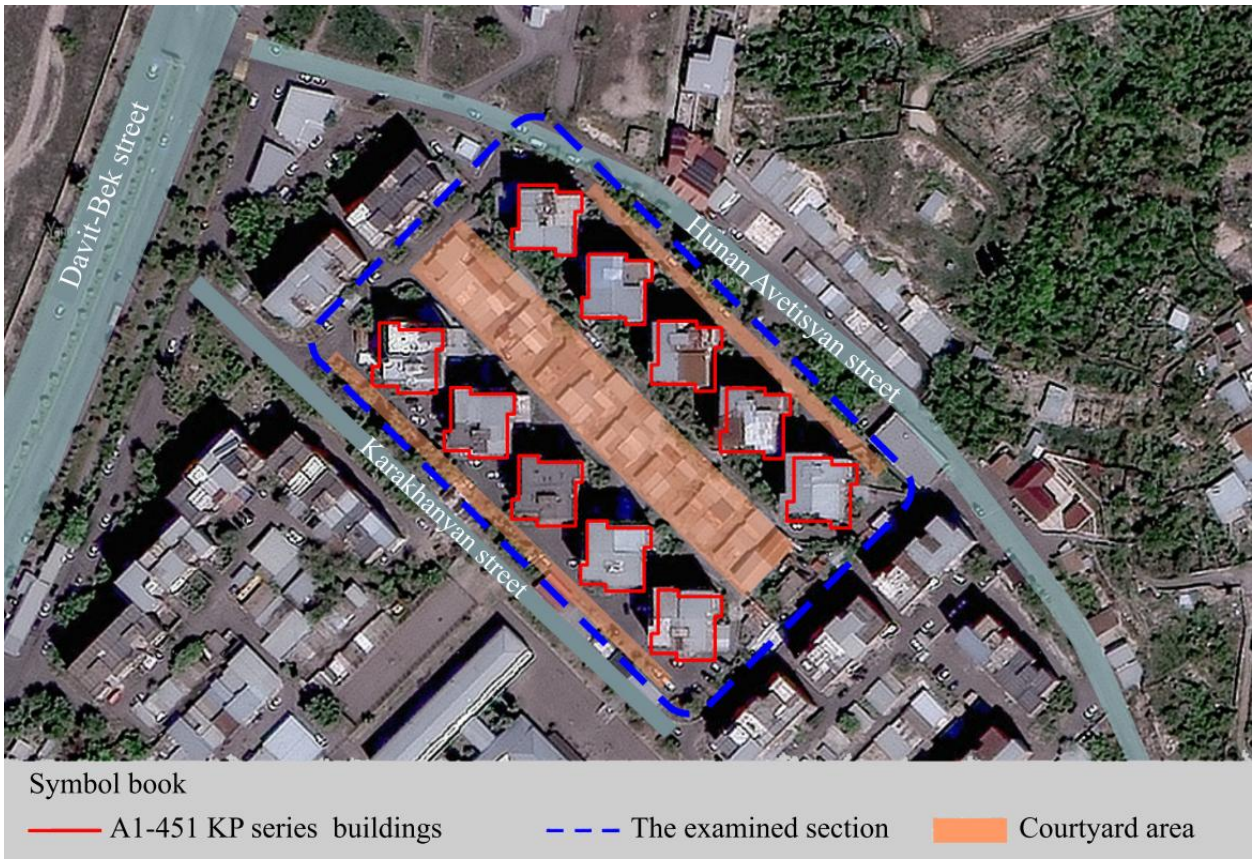


Fig. 5. Analysis of the residential quarter composed of A1-451 KP large-panel buildings located between Davit Bek, Hunan Avetisyan, and Karakhanyan Streets.

Current Situation and Aesthetic Problems. Aesthetic problems in the urban environment refer to the disruption of the volumetric-spatial integrity and harmony of the object and its surroundings. Within the scope of this study, the following were identified in the observed territory: disruption of the aesthetic expressiveness and harmony of A1-451 KP large-panel buildings, including their elements, facades, roofs (the fifth facade), and courtyard spaces.

In the studied area, the aesthetic harmony of the buildings and the environment is disrupted by unauthorized alterations of facades and exterior openings (enlargement, closure, or resizing), balcony modifications (enclosure, extension), and the use of diverse materials and forms during such transformations. On the roofs, a variety of covering materials and forms, arbitrary extensions of upper floors, and additions to the main volumes have further distorted the originally designed appearance of the buildings, undermining their compositional integrity (Fig. 6).



Fig. 6. Problems disrupting the aesthetic harmony of buildings and the environment in the observed area.

The aesthetic integrity of the courtyard environment is compromised by the presence of garages of diverse materials and forms, their unorganized placement, and the addition of private spaces at the expense of shared yard areas through irregular fencing solutions. Children's playgrounds, recreational zones, and green areas are poorly maintained and in an unsatisfactory condition. As a result, the overall compositional integrity and structural subordination of the environment are absent (Fig. 7).



Fig. 7. Problems disrupting the aesthetic harmony of courtyard spaces in the observed area.

Recommendations. In the process of improving the aesthetic quality of buildings, in addition to visual and compositional conditions, it is also necessary to meet contemporary requirements of lifestyle, including social, functional, and ecological solutions. In current conditions, the following methods and approaches may be highlighted for integrated solutions to existing problems:

Double-Skin Facade. The double-skin facade system provides not only aesthetic expressiveness but also fulfills modern functional requirements. A secondary facade, placed at a certain distance from the main facade, creates an air layer that offers multiple operational advantages: thermal control, natural ventilation, sound insulation, daylight regulation, wind buffering, and convenient maintenance opportunities [35].

Facade Color Unification. This approach is characterized by the unification of different materials and colors used in standardized panel buildings, restoring compositional wholeness. The color scheme of facades plays a fundamental role in the visual identity of the urban environment, its attractiveness, as well as certain economic and functional aspects [36]. In the process of shaping the urban image, color-design strategies are essential, integrating the relationship between street functions and building facades. Color design must take into account relations between tones such as harmony and diversity, instead of over-reliance on a single dominant color [37]. Additionally, the introduction of large-scale supergraphics on facades can eliminate monotony and enhance visual distinctiveness. Through this method, panel buildings may be perceived as landmarks for orientation at different distances. The thematic, chromatic, and stylistic selection of supergraphics should depend on the characteristics of the environment, allowing emphasis on its functional, planning, and social significance [38].

Green Facades. This method integrates architecture, environmental protection, and urban revitalization. In addition to addressing aesthetic problems, it also resolves issues of sound and

thermal insulation, improvement of the urban microclimate, reduction of dust levels, and wind buffering. Considering current conditions in Yerevan and the lack of sufficient sound- and heat-insulation measures in standard panel buildings, green facades present an optimal solution. With their high concentration of vegetation and identity as “green surfaces”, they can be applied in different compositional contexts without creating conflict with the surrounding environment [38].

Ventilated Facade Systems. These systems not only introduce modern architectural solutions but also provide thermal insulation, sound insulation, moisture resistance, and fire safety [39].

The modernization process of standard panel buildings must be guided by the Aarhus Convention [40], ensuring civil society’s active participation in environmental formation through access to information and decision-making opportunities.

For the preservation of a favorable environment and sustainable development, it is also necessary to introduce monitoring mechanisms, develop long-term programs, track their implementation, and apply continuous measures for maintaining the visual integrity of the environment.

Results and Discussion

This study formulates a strategic sequence of steps for the modernization of standard-design residential buildings, using the A1-451 KP series as an example. The analysis suggests that the modernization of this series in Armenia requires a comprehensive strategy adapted to local realities. Problems accumulated over decades, physical deterioration, seismic insufficiency, outdated engineering systems, and low resident involvement, have become systemic challenges.

In Yerevan, where standard-design panel buildings constitute a significant share of the housing stock, modernization should be regarded not only as an architectural-structural issue but also as an integral part of urban planning strategy. Special attention should be directed to neighborhoods built with repetitive series designs, which share relatively uniform structures. For instance, through specific cases in districts of Nor Nork, pilot models can be developed that may later be generalized.

International experience demonstrates that effective modernization must be grounded in a multi-criteria assessment of building condition, encompassing technical, economic, social, environmental, and cultural dimensions, and supported by decision-support methods to define optimal modernization options and their sequence [41]. Furthermore, modernization strategies must consider construction-era typologies, which enable targeted refurbishment approaches combining building envelope measures with energy supply system upgrades [42]. Modernization should also be conceived as a long-term, multi-year process, developed through modernization roadmaps that specify the sequence and timing of interventions, while incorporating real-world resource constraints such as shortages of skilled labor and limited energy resources [43]. A further key element is the adoption of a holistic and participatory framework, which integrates residents’ engagement and the collaboration of interdisciplinary expert groups. Approaches such as Soft Systems Methodology (SSM) and Multiple Criteria Decision Making (MCDM) support transparent evaluation and stakeholder learning, thereby ensuring trust and consensus around modernization scenarios [44].

Through these considerations, this study proposes to stimulate political and professional debate that can underpin not only the modernization of individual buildings but also the development of a comprehensive neighborhood-level renovation policy. Using local examples, particularly selected districts of Yerevan, it will be possible to create feasible models that ensure long-term impact. Based on the analysis presented above and the synthesis of international experience, the following strategic recommendations are proposed:

1. Creation of a unified database: Establish a single comprehensive database covering all multi-apartment residential buildings in Armenia. This database should include construction years, structural types, technical condition assessments, seismic risks, documentation of energy-efficiency status, records of any past renovations, and other relevant information. It can serve as a fundamental tool for both policy-making and professional evaluations, as well as for setting priorities.
2. Formation of homeowners' associations (condominiums): Promote the establishment of owners' associations (condominiums) that enable residents to jointly manage, participate, make decisions, and engage in state or donor-funded programs. This requires clarification of the legal framework and provision of organizational support.
3. Development of a modernization methodology: Create a methodology based on both international experience and local professional analyses. This methodology should include phased planning, classification of buildings according to priority, scheduling of actions, and definition of evaluation indicators
4. Local-level audits and planning: Conduct audits and develop specific modernization plans at the neighborhood or building level by applying the developed methodology. These actions are necessary to obtain an accurate technical picture and to make renovation measures more feasible in terms of time and cost. As demonstrated by seismic assessments of buildings in the Avan district [16], local technical audits can identify risks in advance and help prioritize the most vulnerable neighborhoods.
5. Ensuring resident participation: Residents should be involved not only at the information level but also in decision-making, planning, and monitoring phases. Clear tools and mechanisms should be developed to secure active participation through public hearings, residents' representative councils, or digital participatory platforms.
6. Interdisciplinary collaboration: The entire process of developing and implementing renovation programs should involve professionals from multiple disciplines, including architects, builders, engineers, urban planners, sociologists, and lawyers. Such collaboration will enhance the quality and applicability of the programs.
7. Financing and co-financing mechanisms: Develop financing schemes that combine resources from state, municipal, residents, and international donor sources. The roles of responsible institutions should be clarified, ensuring inter-institutional coordination and monitoring functions. This point can also be linked with the broader policy on the maintenance and management of residential buildings, which is the subject of another of our studies.
8. Governance and institutional clarity: Effective implementation of modernization and maintenance processes requires a clear governing authority or the improvement of existing structures. The model of involvement of state, municipal, and private entities should be revised, including the distribution of powers, monitoring mechanisms, and legal frameworks. The current analysis also confirms the necessity of a well-defined governance system.

Conclusion

Yerevan's housing stock, dominated by standard-design residential buildings, faces urgent modernization needs due to accumulated structural, seismic, and energy-efficiency challenges. At present, responsible institutions lack sufficient capacity and resources to fully address these problems, leaving much of the housing stock vulnerable. Building on systematic studies and international experience, and grounding the analysis in a representative case study of A1-451 KP series buildings

(to make the problems and solutions more concrete), this article has outlined methodological, architectural, seismic, and energy-efficiency pathways. The findings emphasize that only through coordinated, evidence-based strategies can Armenia secure a sustainable and resilient future for its residential buildings. At the same time, the results of the conducted research raise a number of new questions, such as the absence of a unified platform or database on residential buildings (creation of a unified database), the formation and operation of homeowners' associations (condominiums), the mechanisms for ensuring resident participation, the issues of financing and co-financing, as well as governance and institutional clarity. The outcome of the research provides scientifically grounded recommendations aimed at improving the technical and aesthetic performance of standard-design panel buildings, which can be applied within reconstruction and modernization programs implemented by state and local government authorities. Nevertheless, further questions arise concerning the eight proposed strategic directions: (1) creation of a unified building database, (2) formation and effective operation of homeowners' associations (condominiums), (3) development of a national modernization methodology (phasing, prioritization, scheduling, indicators), (4) local-level audits and plans at neighborhood/building scales, (5) mechanisms to ensure resident participation in decisions, planning, and monitoring, (6) institutionalized interdisciplinary collaboration across architecture, engineering, planning, economics, law, and social sciences, (7) financing and co-financing schemes combining state, municipal, resident, and donor resources with clear coordination and oversight and (8) governance and institutional clarity regarding mandates, powers, monitoring, and legal tools. We believe that the results of this study can be useful for guiding the modernization process of residential buildings constructed in Yerevan and other cities of the Republic of Armenia.

Author Contributions

Conceptualization, M.K.; methodology, M.K., S.S. and A.M.; formal analysis, M.K., M.S., S.S. and A.M.; investigation, M.K.; writing original draft preparation, M.K., M.S., S.S. and A.M.; writing review and editing, M.K.; visualization, M.S. All authors have read and agreed to the published version of the manuscript.

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Data Availability

The data generated and analyzed during this study are available from the corresponding author upon reasonable request.

Competing Interests

The authors declare no competing interests.

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