Post-War Urban Development of Large-Scale Housing Estates in Ukraine in the 1980s: Potentials and Prospects

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vhw Forschung

IMPRESSUM

Fördergeber
vhw – Bundesverband für Wohnen und Stadtentwicklung e. V.
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Gestaltung
Druckerei Franz Paffenholz GmbH, Bornheim

Berlin/Potsdam, Juni 2025

Zitierhinweis
Antonenko, N. (2025): Post-War Urban Development of Large-Scale Housing Estates in Ukraine in the 1980s: Potentials and Prospects. vhw Abschlussbericht. Berlin.

VORWORT

Die vorliegende Studie von Dr. Nadija Antonenko befasst sich mit der Analyse von Großsiedlungen der 1980er Jahre in der Ukraine und der DDR. Vor dem kulturellen Hintergrund osteuropäischer Stadtentwicklung im späten 20. Jahrhundert bringt die Autorin ihre Expertise in den Bereichen Stadtplanung, Architektur und Resilienzforschung ein, um zukunftsorientierte Potenziale und Perspektiven dieser Großsiedlungen zu untersuchen. Ihre Studie ist das Ergebnis intensiver Forschung und praktischer Erfahrungen, die sie im Rahmen früherer Förderprogramme an der Universität Kaiserslautern sowie im Rahmen ihres einjährigen Stipendiums (2023/24) bei der vhw Stiftung des Bundesverbandes für Wohnen und Stadtentwicklung gesammelt hat, um daraus innovative Ansätze für eine nachhaltige und resiliente Stadtentwicklung abzuleiten.

Die Studie bietet einen vergleichenden Blick auf die Entwicklungsbedingungen von Großsiedlungen der 1980er Jahre in der Ukraine und in Ostdeutschland, wobei die Autorin die Auswirkungen der Wohnungsbaupolitik, räumlich-morphologische Strukturmerkmale sowie prägende soziale und wirtschaftliche Dynamiken einbezieht, die für eine Resilienz bedeutsam erscheinen. Durch die Analyse differenzierter Quartiere in beiden Ländern bzw. Landesteilen, werden wertvolle Erkenntnisse gewonnen, die zur Entwicklung nachhaltiger Ansätze in der Stadtentwicklung beitragen. Ein zentraler Aspekt der Studie ist die Bewertung der urbanen Resilienz gegenüber globalen Bedrohungen und Herausforderungen wie Klimawandel, soziale Ungleichheit oder Vertreibung und Flucht. Die Autorin zeigt auf, wie die tragischen Ereignisse in der Ukraine zugleich die Chance bieten, den Zustand der Städte neu zu denken und neue Ansätze für urbane Resilienz zu entwickeln.

Dr. Antonenko erarbeitet nachfolgend eine detaillierte Methodik zur Bewertung urbaner Resilienz, die auf Widerstandsfähigkeit räumlicher Strukturen gegenüber Herausforderungen rekurriert. Aus einem Abgleich zwischen realen und idealen Resilienzmerkmalen werden konkrete Empfehlungen für die Stadtplanung, Politikgestaltung und Öffentlichkeitsbeteiligung abgeleitet. Der resultierende akademische und praxisnahe Impuls erfährt im Kontext der aktuellen weltpolitischen Lage eine fast in Vergessenheit geratene, besondere Bedeutung.

Neben der deutschsprachigen Kurzfassung, die als vhw werkSTADT erscheinen wird, haben wir uns entschlossen, die Langfassung in englischer Sprache zu veröffentlichen, um sie online einer internationalen Community zugänglich zu machen. Wir danken Dr. Antonenko für ihre engagierte und tatkräftige Forschungsarbeit, die für die vhw Stiftung und die Kolleginnen und Kollegen im Bundesverband neben den angeregten Debatten auch eine interessante kulturelle und fachliche Bereicherung erbracht haben. Wir wünschen Dr. Antonenko an dieser Stelle in einer schwierigen weltpolitischen Zeit und bei den damit verbundenen Herausforderungen alles erdenklich Gute auf ihrem weiteren beruflichen und privaten Lebensweg.

Dr. Thomas Kuder
Seniorwissenschafter vhw e. V.

FOREWORD

This study by Dr. Nadija Antonenko analyzes large housing estates built in Ukraine and the GDR in the 1980s. Against the cultural backdrop of urban development in Eastern Europe in the late 20th century, the author draws on her expertise in urban planning, architecture, and resilience research to examine the future potential and prospects of these large housing estates. Her study is the result of intensive research and practical experience gained during previous funding programs at the University of Kaiserslautern and during her one-year scholarship (2023/24) at the vhw Foundation of the Federal Association for Housing and Urban Development, with the aim of deriving innovative approaches for sustainable and resilient urban development.

The study offers a comparative view of the development conditions of large housing estates of the 1980s in Ukraine and eastern Germany, with the author taking into account the effects of housing policy, spatial-morphological structural features, and formative social and economic dynamics that appear to be significant for resilience. By analyzing differentiated neighborhoods in both countries or parts of the country, valuable insights are gained that contribute to the development of sustainable approaches to urban development.

A central aspect of the study is the assessment of urban resilience to global threats and challenges such as climate change, social inequality, displacement, and flight. The author shows how the tragic events in Ukraine also offer an opportunity to rethink the state of cities and develop new approaches to urban resilience.

Dr. Antonenko then develops a detailed methodology for assessing urban resilience, which draws on the resilience of spatial structures to challenges. Concrete recommendations for urban planning, policy-making, and public participation are derived from a comparison between real and ideal resilience characteristics. In the context of the current global political situation, the resulting academic and practical impetus takes on a special significance that had almost been forgotten.

In addition to the German-language summary, which will be published as vhw werkSTADT, we have decided to publish the long version in English to make it available online to an international community.

We would like to thank Dr. Antonenko for her dedicated and energetic research work, which has not only stimulated lively debate but also provided interesting cultural and professional enrichment for the vhw Foundation and our colleagues in the Federal Association. At this point, we would like to wish Dr. Antonenko all the best for her future professional and personal life in these difficult times of global politics and the challenges they bring.

Dr. Thomas Kuder
Senior Scientist vhw e. V.

INHALT

1 Acknowledgments

I would like to express my sincere gratitude to VHW for their comprehensive support in the implementation of this research, with special thanks to Prof. Dr. Jürgen Aring, Dr. Thomas Kuder, and the entire VHW team. I am also deeply grateful to Prof. Dr. Detlef Kurth for his guidance and for the opportunity to collaborate with RPTU Kaiserslautern-Landau.

I extend my appreciation to the experts who generously shared their time for discussions and consultations: Prof. Dr. Sigrun Kabisch (UFZ), Prof. Dr. Uwe Altrock (Kassel University), Dr. Matthias Bernt (Leibniz Institute for Research on Society and Space – IRS), Prof. Holger Schmidt (RPTU Kaiserslautern), Prof. Sc. Dr. Kostiantyn Mezentsev and Dr. Nataliia Provotar (Taras Shevchenko National University of Kyiv), Prof. Sc. Dr. Oleksandr Buriak (University of Lodz), Prof. Sc. Dr. Ihor Pylypenko and Prof. Sc. Dr. Ivan Moisienko (Kherson State University), Prof. Dr. Oliver Fehren (ASH Berlin), Prof. Anke Schmidt (RPTU Kaiserslautern-Landau), Dr. Nico Grunze, Dr. Arvid Kruger (Kassel University), Dr. Henning Boeth (Senate Department for Urban Development, Berlin), Dr. Liutauras Nekrošius (Vilnius Tech), Dipl.-Ing. Ben Gabriel (TU Berlin), Dipl.-Ing. Thomas Helfen (Stadtkümmerei GmbH), Mr. Luisgang (WBG Kontakt), Jana Reinsch (Office of Housing and Urban Renewal, Leipzig), Susan Engel (QM Falkenhagener Feld Ost), Janine Poßneck (UFZ), Serhii Diachenko (NGO Urban Re-Public), Tinatin Gurgenidze (Tbilisi Biennale), and Kherson residents (Andriy Lutsik, Iryna Lopushynska, Andriy Lopushynskyi, Svitlana Duminska, and Dementiy Bily).

A special thank you goes to the urbanists, architects, and students who supported the research through data collection and participation in the experimental design process, including Tetiana Rumilets, Anna Kuzyshyn (RPTU Kaiserslautern-Landau), Dr. Liudmyla Shvets (O.M. Beketov National University of Urban Economy in Kharkiv), and students from ODASA, KNUBA, and O.M. Beketov NUUEK.

2 Large-scale housing estates in Ukraine and the full-scale war: rationale and research objectives

In recent years, cities around the world have been facing a wide range of threats — from natural disasters and pandemics to economic inequality and migration. Climate change, which increases both the frequency and severity of such disasters, is increasingly viewed as irreversible, necessitating a shift toward more resilient strategies. Since 2022, global military threats have also emerged: the war in Ukraine has disrupted the post-World War II balance and reshaped the global order. The tragic events unfolding in Ukraine offer a critical opportunity to reconsider the overall condition of cities and to develop new approaches to urban resilience and vulnerability. The challenges Ukrainian cities are enduring may contribute to the creation of universal strategies for a safe, dignified, and sustainable urban future.

A key issue in the post-war recovery of Ukrainian cities, situated within the broader discourse on urban resilience. The most problematic and vulnerable areas are the large-scale housing estates constructed in the late 1970s and 1980s. These neighbourhoods are characterised by increased building heights, higher development density, a reduced provision of everyday and socio-cultural services, underdeveloped green infrastructure, and a marked rise in informal construction after 1991. The complex challenges that remained unresolved in Ukrainian post-socialist cities over the three decades following the collapse of the Soviet Union have been critically exacerbated by ongoing military conflict, resulting in varying degrees of urbicide, ecocide, and genocide (Palekha et. al, 2024).

This study aimed to analyse transformational strategies and processes of spatial regeneration and neighbourhood transformation in large-scale housing estates in Ukraine and Eastern Germany from the 1990s to the 2020s, to assess their current resilience to real global threats, and to propose approaches for redefining 1980s-era neighbourhoods in post-war Ukraine as sustainable and resilient urban territories.

The study was conducted through a detailed examination and comparison of the spatial characteristics of selected neighbourhoods in large-scale housing estates from the 1980s in cities of Ukraine and Eastern Germany. This comparative approach made it possible to identify the spatial features of the morphotype itself and to determine the specific attributes of large-scale housing estates in Ukraine.

The main objectives of the study were as follows:

- To compare the development conditions of 1980s neighbourhoods in Ukraine and Eastern Germany, identifying both differences and common features.
- To determine the impact of national and municipal housing policies on the principles of regeneration of 1980s residential neighbourhoods in Ukraine and Eastern Germany from the 1990s to the 2020s;
- To identify the actual spatial characteristics of 1980s residential neighbourhoods in Ukraine and Eastern Germany and assess their resilience to contemporary global threats;
- To propose changes in urban planning approaches for large-scale housing estates in Ukraine aimed at effective post-war regeneration.

It is important to acknowledge that today's threats, especially those caused by war, have no clear historical parallels. As a result, many emerging solutions are experimental and must be tested and refined in real conditions. This study's key findings aim to support future efforts to enhance the resilience of Ukrainian cities.

The analysis involved collecting actual parameters and qualitatively assessing them against the ideal spatial resilience characteristics. Field research played a significant role in gathering empirical data, including trips to Berlin, Leipzig, Halle, and Dresden. The necessary data on Ukrainian neighbourhoods were collected with the help of university students from Odesa, Kyiv, and Kharkiv; data on Kherson were obtained through a series of in-depth interviews with residents.

3 Historical development of large-scale housing estates in Ukraine and Germany in the 1980s

The construction of large-scale housing estates in the 1980s, both in the German Democratic Republic (GDR) and in Ukraine, took place during a critical period marked by the evident failure of the centrally planned economic model and the imminent collapse of the communist system of governance in the Soviet Union (Zatlin, 2007). The attempt to establish fully realized communist states ultimately proved unsuccessful (Jarausch, 1993). Growing public dissatisfaction was fueled by increasingly entrenched bureaucratic and corrupt decision-making mechanisms (Orenstein, 1995). In terms of bureaucratization, the Ukrainian Soviet Socialist Republic became one of the "most Soviet" of all Soviet republics, where decisions — whether at the everyday or republican level— were often blocked by irresolvable institutional contradictions and had to be circumvented "through party connections" or resolved "unofficially" (Wilson, 2009). Similar phenomena were observed in the GDR, where the speed and quality of decision-making increasingly depended on the personal inclinations and competencies of individual officeholders (Fulbrook, 2005).

The ideological and economic challenges faced by socialist countries during this period significantly influenced both the spatial development and the aesthetic, planning, and architectural approaches to residential districts — the emblematic construction projects of socialism. Despite certain differences in the political and economic contexts of these countries, the core approaches to housing development in the 1980s in both the GDR and Ukraine shared several common features. This period was marked by more intricate spatial compositions within residential areas, sometimes excessively formalised, alongside a search for architectural individuality, postmodern stylistic elements, and symbolic forms (Hatherley, 2015). These tendencies emerged despite ongoing efforts to reduce costs, streamline processes, and accelerate design and construction workflows.

The primary actors in construction technology during the 1980s in both Soviet Ukraine and the GDR were the house-building combines—large industrial enterprises responsible for the mass production of prefabricated building components. The presence, number, proximity to construction sites, production capacities, and range of manufactured products of these combines defined the framework within which urban planners and architects could operate. Within the context of the socialist economy, construction technologies were actively developed and improved, enabling the acceleration of the building process. However, this often came at the expense of the overall quality and functionality of the constructed buildings (Antonenko, 2024).

In the 1980s, the "environmental approach" gained broader prominence in urban planning. In the design of housing estates, significantly greater attention was paid to natural and historical contexts. Project decisions increasingly took into account the characteristics of the natural landscape, the location of water bodies, and the existing structure of green spaces, which were incorporated into the development of multi-level green frameworks. In the GDR, in addition to natural factors, historical context played a crucial role. Unlike the urban planning practices in Soviet Ukraine, where large-scale housing estates were primarily built on the urban periphery, German cities saw extensive redevelopment in central and historically significant urban areas. German architects actively integrated historical elements into the layout of new residential complexes, allowing modern buildings to be harmoniously embedded within the existing urban fabric while respecting the architectural heritage. This approach in the GDR emphasised the preservation of historical identity, whereas in Ukraine, the primary objective was to create comfortable living environments with a strong focus on the surrounding natural landscape.

The morphological development of large-scale housing estates in Ukraine and East Germany during the 1980s also exhibited notable differences. In Ukraine, particularly in regional centres, the scale of newly constructed residential complexes was significantly larger than in the GDR. Ukrainian housing estates typically housed between 250,000 and 350,000 residents, whereas in East Germany, such districts generally accommodated no more than 100,000 people.

In terms of spatial composition and planning principles, Ukraine continued to develop neighbourhoods characterised by free-form layouts typical of the 1970s. Series-produced housing blocks were often arranged into more complex curvilinear configurations, creating diverse open spaces; different building series were combined, and individual non-standard architectural elements were designed. Building heights continued to increase, reaching up to 25–30 stories. In contrast, during the same period in the GDR, there was a departure from free-form layouts, replaced by block development featuring straight streets and semi-enclosed courtyards. Building heights were reduced to 5–6 floors. This form of development enabled denser and more structured use of urban land, thereby enhancing functionality and improving living conditions (Anisimov, 2019).

One significant aspect that emerged in the construction of large-scale housing estates during the 1980s was the lack of adequate funding for social facilities and infrastructure. Whereas in the 1960s and 1970s the construction sequence typically involved the simultaneous development of residential buildings alongside kindergartens, schools, hospitals, cultural centers, and other public buildings, as well as the landscaping of the surrounding areas before the residential buildings were commissioned (French, 1995), in the 1980s new Ukrainian districts often entered operation without completed landscaping of courtyards and access roads, and with unfinished schools and kindergartens. The construction of public facilities was frequently postponed in favour of increasing the total residential floor area. As a result, by the end of the decade, many social buildings remained incomplete, and in some districts, undeveloped, vacant plots – "empty lots" – became evident. This issue was particularly pronounced in Ukraine but was also present in the GDR.

In large cities, tram and bus networks were actively expanded, and new metro stations were constructed, providing residents with more accessible and environmentally friendly modes of transportation. Within residential neighbourhoods,

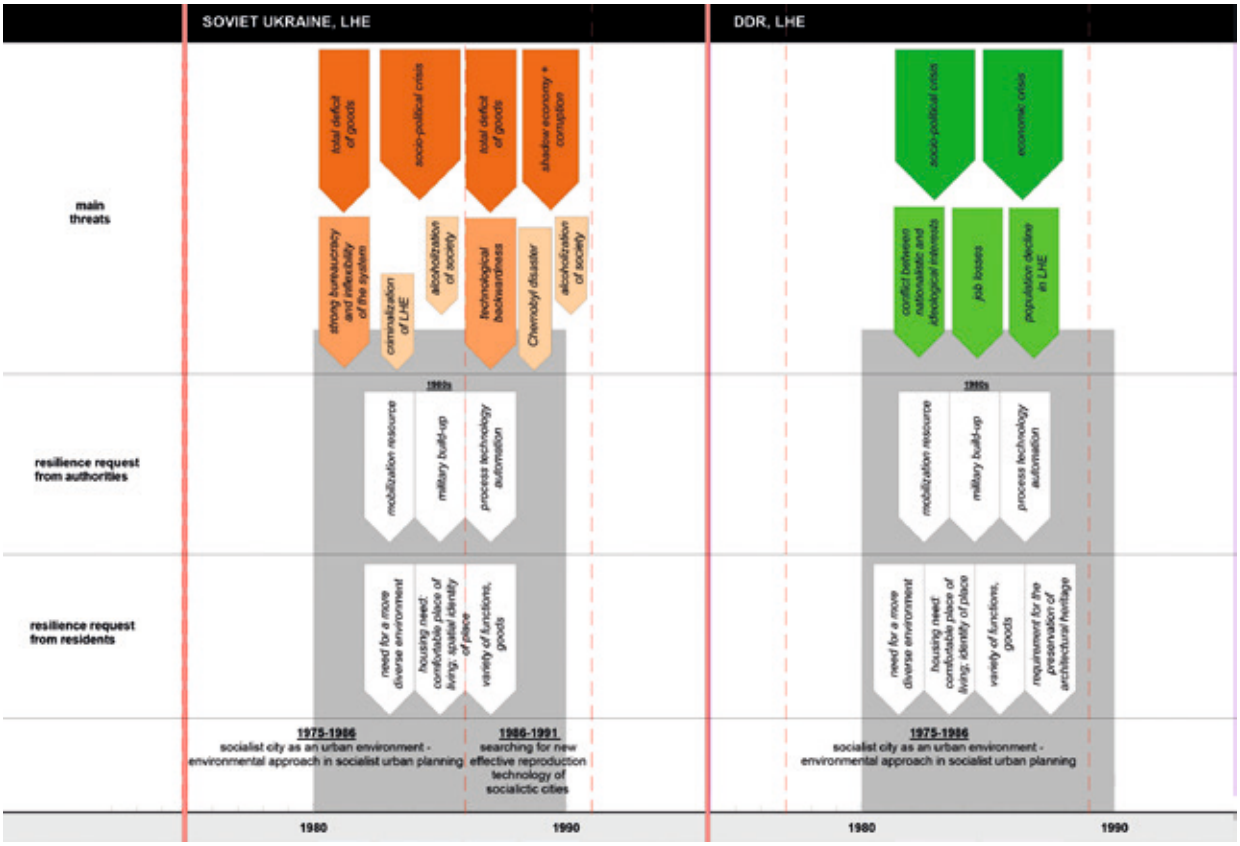

Fig. 1 *Major threats to large-scale housing estates in the 1980s. Diagram by Nadiia Antonenko*

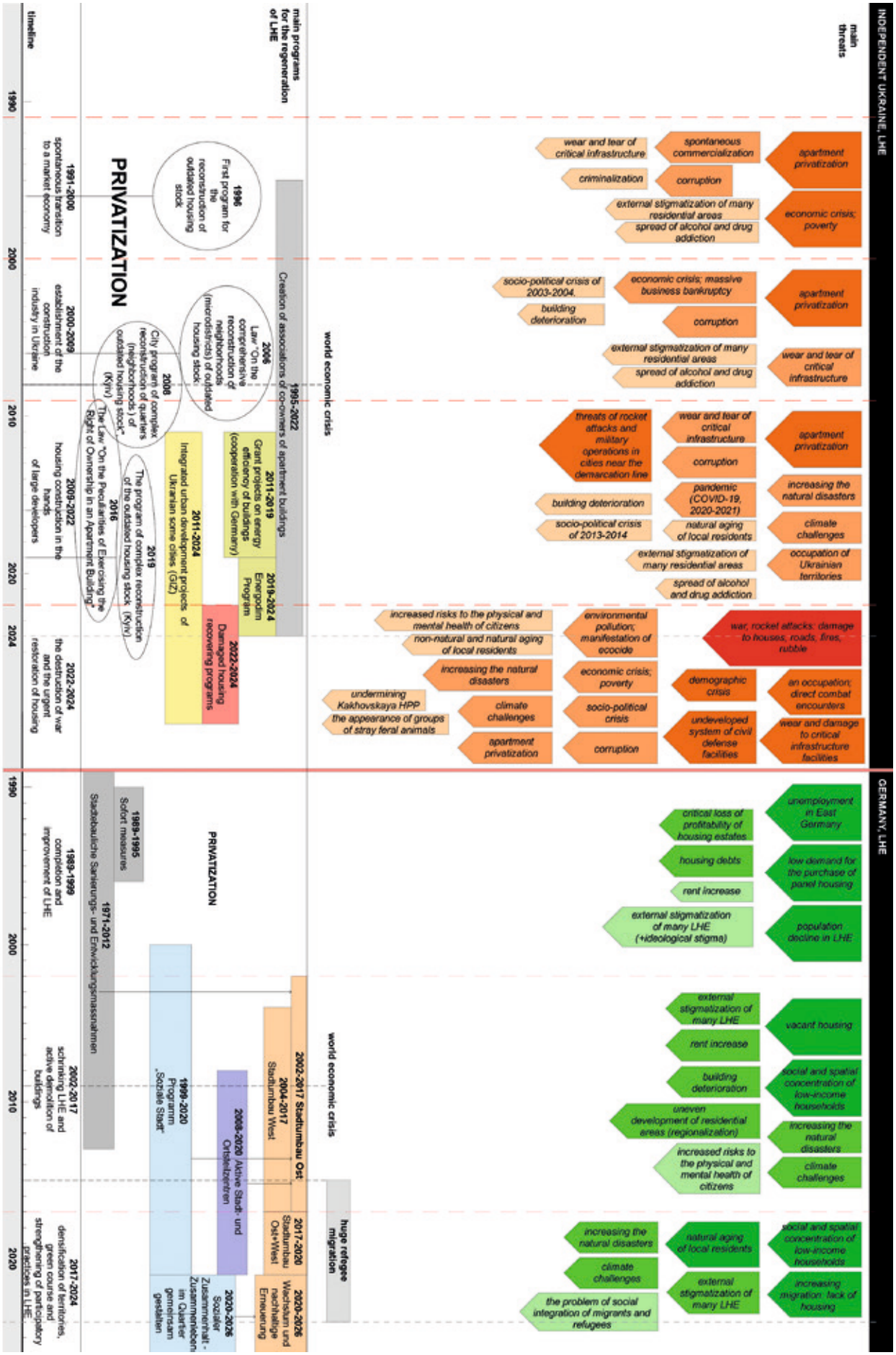

Fig. 2. *Key threats to large housing estates in Ukraine (1991–2024) and Germany (1989–2024), and state programs in response to them. Diagram by Nadiia Antonenko*

particular attention was given to the design of pedestrian public spaces such as squares, promenades, and courtyards.

In the 1980s, changes also occurred in the aesthetics and architectural solutions of residential buildings. In Ukraine, the period was characterised by geometric abstract forms typical of the late wave of modernism. There was an exploration of plastic expression in the details of the residential buildings themselves, such as balcony railing surfaces and stairwells, with active use of colour and texture contrasts. Additionally, regional ethnic motifs became more explicitly reflected in façade designs. In the GDR, large-scale housing estates built in central urban areas during the 1980s featured façade panels that imitated historical forms. Both in Ukraine and East Germany, art objects were actively integrated into residential spaces, including sculptures, fountains, steles, mosaics, bas-reliefs, and stained glass were frequently employed (Fig. 1).

Since the early 1990s, the trajectories of spatial development in the large-scale housing estates of the former German Democratic Republic (GDR) and independent Ukraine have diverged significantly. The differing paths of their transformational processes were driven by distinct sets of external threats and varying decision-making mechanisms concerning changes in the spatial organisation of districts. Changes in Ukrainian large-scale housing estates generally represented spontaneous reactions to emerging threats. In contrast, in East Germany, transformations were the result of the long-term implementation of nationwide programs. The following transformational periods can be identified for the housing estates of the 1980s in both East Germany and Ukraine (Fig. 2):

1) The first transformational stage (1991–2000 in Ukraine and 1989–1999 in East Germany) represented an adaptive response of the existing spatial structure of large 1980s residential districts to new market conditions.

In East Germany, the further development of panel housing projects was abruptly halted, and prefabricated housing factories were closed (Häußermann, Hartmut & Walter Siebel, 1996). Monitoring and design initiatives were undertaken to renovate the large residential areas of the 1980s to make them suitable for full urban living (Bernt&Holm, 2013). Measures taken before 2000 focused on improving public and courtyard spaces, landscaping, cleaning adjacent territories, and demolishing certain buildings and structures.

In Ukraine, the slow completion of Soviet-era projects and the construction of standardised housing intended for preferential social groups continued until 2000 (Mykhnenko & Swain, 2010). Prefabricated housing factories gradually closed; some were acquired by private companies, technologically upgraded, and have survived as construction industry enterprises to this day. Vacant lots, where residential buildings and public facilities remained unfinished, rapidly turned into neglected wastelands, often used as pedestrian passages or spontaneously occupied by local businesses for paid garage cooperatives, parking lots, and marketplaces. Informally organised trade points in areas of high foot traffic developed into markets that served both as primary sources of essential goods and as workplaces for much of the population in these districts during the 1990s. Funding for housing maintenance services was insufficient, resulting in only partial upkeep of the territories. During this period, the process of individual apartment privatisation also accelerated.

2) The second transformational period in Germany (2002–2017) was marked by the implementation of the Stadtumbau Ost program, which involved the rethinking and reconstruction of hundreds of large-scale housing estates, including those built in the 1980s.

According to the results of these initiatives, significant transformations occurred in German residential areas during the 1990s. Primarily, there was extensive demolition of residential buildings accompanied by the relocation of residents, often resulting in a reduction of the original size of the housing estates. Partial morphological changes in existing developments took place, including the integration of new architectural structures designed in contemporary styles. Special attention was given to the reconceptualisation and redevelopment of central spaces within the residential districts: peripheral functions were minimised, and the main activity concentrated in public centres, where elements of tactical urbanism began to appear. Simultaneously, deliberate removal of spatial ideological markers and symbols occurred, from individual artworks to entire buildings and organisational-spatial structures. A key focus was placed on fostering an inclusive urban environment. Gradual renovation of the housing stock was carried out with an emphasis on improving energy efficiency. Additionally, there was a reduction in automobile traffic and the development of pedestrian and bicycle infrastructure. Considerable importance was also given to strengthening water-green frameworks and searching for new spatial identities oriented toward contemporary principles of sustainable and comfortable urban development.

The second transformational period in Ukraine (2000–2009) was characterised by the establishment of stable

criminal-political governance frameworks. The majority of large enterprises were privatised, and spheres of control and influence were distributed among key influential groups (Puglisi, 2003). Opportunities emerged for organising and conducting larger-scale and networked businesses, including the expansion of foreign company networks.

For residents of residential districts, these processes manifested in a number of spatial changes. Informal markets transformed into permanent commercial spaces with both permanent and temporary structures. Vacant department stores and service centres were purchased by representatives of large and medium-sized network businesses, which contributed to improved service quality. Relative economic stabilisation allowed part of the population to raise their living standards, reflected in active apartment resales, an increase in car ownership, and spontaneous construction of garages on public and adjoining lands, while the social structure of the districts remained fairly diverse. The number of small businesses increased significantly: on the ground floors of residential buildings, especially near public transport stops, beauty salons, shops, and offices opened en masse. Construction activity resumed in the form of infill development: new high-rise residential and public buildings, most often commercial or religious, appeared on vacant lots and in parks. Car ownership intensified, manifested by the spread of informal parking in public neighbourhood spaces. The public transport system also changed, remaining mostly private and uncoordinated at the systemic level. The socio-cultural function of residential districts was in decline. Water-green frameworks lost their former quality: their area decreased, vegetation had low aesthetic and ecological value, and maintenance was severely insufficient. Alongside this, spontaneous architectural transformations took place, including unauthorised apartment renovations, additions, conversions of residential premises to non-residential uses, and patchwork repairs. Despite these negative trends, sustainable forms of self-sufficiency in necessary resources and internal and external transport connections with the city were established, ensuring the viability of the districts. It was during this period that the first associations of co-owners of apartment buildings (OSBB) began to form, aimed at creating more effective mechanisms for building management and maintenance of adjacent territories.

3) The third transformational period for the large-scale housing estates of the 1980s in Eastern Germany began in 2017 and continues to the present day. The primary challenge of this period has been the sharp increase in refugees and labour migrants arriving in the country. Large housing estates, predominantly consisting of social housing, have seen active settlement by low-income foreigners (Kabisch&Pössneck, 2022). There has been a catastrophic shortage of residential buildings as well as associated public facilities such as schools, kindergartens, and community centres.

Another significant threat to these residential areas has been the consequences of climate change, which have particularly impacted developments with large inter-building open spaces. This has necessitated a rethinking and strengthening of water-green frameworks, as well as the transformation of public spaces and building facades to address new climatic challenges. Urban gardening has been supported and developed as an environmentally and socially oriented initiative. Residential density has increased through the construction of new housing and socio-cultural infrastructure facilities. Renovation efforts have been actively pursued, focusing on enhancing buildings' energy efficiency and inclusivity. The territories of these districts have been re-evaluated from the perspective of climate resilience, with projects implemented to improve local microclimates. New public functions have been introduced, including live laboratories and tactical urbanism, involving active participation from residents. Considerable attention has also been paid to reimagining and renewing courtyard spaces, as well as developing new mobility plans within broader citywide strategies. All these processes have been accompanied by a search for new spatial and symbolic identities for the residential districts.

In Ukraine, the third transformational period (2009–2022) was characterised by the emergence and domination of the housing construction market by large development companies (Pomortseva, Kobzan, & Pankin, 2024). General city plans were modified to meet the needs of major developers, resulting in the repurposing of various urban territories. Spot development of individual high-rise buildings and small residential complexes adjacent to existing districts gave way to large-scale construction of new quarters comprising dozens of multi-story buildings. Developers economised on social infrastructure construction—schools, kindergartens, and clinics within large-scale housing estates have been subjected to increased loads. The functional composition of the districts became more diverse: facilities targeting wealthier consumers appeared, such as shopping and entertainment centres, restaurants, building supply stores, fitness centres, and beauty salons. A critical shortage of socio-cultural infrastructure persisted: new clubs, educational, and cultural institutions were rarely constructed, and commercial establishments could not satisfy the population's social needs. Public

spaces increasingly became sites of informal parking. Architecturally, there was fragmented, unsystematic façade insulation, which disrupted the visual integrity of the housing environment. Despite these challenges, some positive changes were noted: communal maintenance of green zones improved, reconstructions of school and kindergarten grounds, squares, and parks were undertaken, and playgrounds were modernised. However, systemic overhauls of infrastructure were not carried out, leading to an increase in emergency incidents and further degradation of the urban environment. There was significant technical deterioration of buildings and critical infrastructure, population ageing, a lack of inclusive environments, and excessive use of existing social facilities without adequate compensation from developers. Automobile dependence intensified, while public transport remained unable to cope with growing passenger flows.

4) Due to the full-scale Russian invasion of Ukraine in 2022, the third transformation period was interrupted. Construction of new residential quarters practically stopped (Bobrova, 2023). However, large-scale housing estates faced new critical threats: destruction of houses and buildings caused by missile and artillery shelling, destruction of critical infrastructure, humanitarian catastrophe, rising poverty, demographic crisis, and increasing numbers of people with physical and mental health issues.

Spatial transformations of large-scale housing estates caused by the war manifested unevenly depending on the geographic location of a specific neighbourhood relative to the frontline. For example, districts of Kharkiv, Kherson, Zaporizhzhia, and settlements in the Donetsk region were most vulnerable to direct destruction due to missile strikes and artillery shelling. At the same time, in Kyiv and western cities located far from the active combat zone, people suffer from periodic missile and drone attacks and the lack of heating, electricity, and water supply caused by damage to individual critical infrastructure facilities.

In frontline cities, the occupancy level of residential buildings has significantly decreased: a large part of the population was forced to leave their homes and move to safer regions. Spatial changes included partial or complete destruction of residential buildings and extremely slow rates of their restoration, even when technical conditions allowed for renovation. The number of operating enterprises and service facilities sharply decreased, and a significant portion of sociocultural institutions closed. One of the key vectors of spatial restructuring was the construction or repurposing of existing buildings into civil defence facilities—shelters, bomb shelters, and resilience centres. Transportation activity also changed: in some cases, there was a sharp reduction in movement, in others, destabilisation of logistics connections. The state of water-green frameworks worsened, which is further complicated by global climate change. The social and medical infrastructure in the residential areas of western Ukraine experienced overload.

Despite these acute challenges caused by the war, the residential areas built in the 1980s in Ukrainian cities continue to function as housing territories for hundreds of thousands of Ukrainians.

4 Methodological framework for studying the urban resilience of large-scale housing estates

Since the 1970s, the concept of "urban resilience" has been used in a limited context—primarily within research related to ecology, climatology, and psychology (Folke, 2006; Adler, 2000; Gunderson & Holling, 2002). However, with the growing intensity and globalisation of threats since the early 2000s (UNISDR, 2005), the concept has increasingly appeared in political science, sociology, economics, and urban policy studies (Meerow & Newell, 2016; UN-Habitat, 2012). In the fields of urban planning, urban design, and architecture, "urban resilience" remains a relatively new concept and is currently undergoing theoretical and methodological development, defining its scope, structure, core characteristics, as well as the development of tools and technologies (Sharifi & Yamagata, 2016; Jabareen, 2013).

In German-speaking discourse, the concept of urban resilience has gained significant momentum and entered the practical realm of urban planning and architecture primarily after the COVID-19 pandemic. The rapid spread of the virus and the inability of healthcare infrastructure to quickly adapt to the threat not only had a major impact on global and national economic processes, but also transformed patterns of social interaction and their expression in the physical forms of the city—such as changes in the organization of public green spaces (Honey-Rosés et al., 2020), the rising relevance and spread of the "15-minute city" concept (Moreno et al., 2021), adjustments in the spatial design of public buildings (Megahed & Ghoneim, 2020), and the rethinking of medical facility networks (Sharifi, A., & Khavarian-Garmsir, 2020). An important milestone that solidified the foundational understanding of urban resilience was the development and presentation of the "Urban Resilience" memorandum (BMI, 2021) at the 14th Federal Congress. This event made a significant contribution to embedding the concept into Germany's national urban development policy (BBSR, 2024).

Urban resilience—a term that was relatively unfamiliar in pre-war Ukrainian academic circles—gained widespread traction following the full-scale Russian invasion of Ukraine. Its dissemination was primarily linked to the emergence of numerous direct and indirect support programs for Ukraine from European and American countries (USAID, 2022; UNDP, 2022). Within a short period, the concept of "urban resilience" entered the political and social discourse, while simultaneously developing rapidly within the academic field. Unlike the German understanding of multi-component urban resilience and its integration into the broader concept of urban sustainability—associated with high-quality urban life (Neue Leipzig-Charta, 2020; European Commission, 2019)—in Ukraine, under the conditions of intense military conflict, the term "urban resilience" has been interpreted more narrowly as "urban survivability" (Chelashvili et al., 2025; OECD, 2022).

The methodology of this study was based on the concept of urban resilience as a four-component system, with its core elements being governance, participation, economy, and environment (Arup, 2019; Chelleri et al., 2016). It was assumed that the characteristics of the built urban environment and the tools of urban planning (including urban design and the architecture of buildings and structures) are part of the "environment" component, which also includes the diversity of natural and ecological features of the urban area. The normative framework for ideal spatial characteristics of urban resilience was grounded in the concept of normal urban life, as outlined in key documents on urban development—such as the Sustainable Development Goals (UN, 2015), the New Leipzig Charter (Neue Leipzig-Charta, 2020), and the Green Deal (European Commission, 2019) — which serve as reference points for European urban planners and architects in their design decisions. A key document underpinning the normative basis in this study is also the Universal Declaration of Human Rights (United Nations,

1948), which provides a foundational framework for human-centred and democratic decision-making in acute crisis and survival situations (Fig. 3).

The basis for determining the boundary values of spatial characteristics, assessed from the perspective of resilience, was also the principle of sufficiency. This approach correlates with the concept of "sufficiency scenarios" proposed in sustainable urban planning (Princen, 2005), as well as with the idea of "sufficient urbanism," in which sustainable development is seen as the search for a balance between needs, environmental possibilities, and societal expectations (Raworth, 2017). Within these theories, sufficiency is understood as the threshold of a reasonable level of resource consumption and urban environmental quality necessary to ensure a decent life without excessive growth or over-intervention.

In this study, the principle of sufficiency was used as a tool for calibrating spatial parameters based on their minimally required level to ensure the basic resilience and stability of the environment. It is important to note that the concept of sufficiency is not universal; it requires detailed empirical validation, as its boundaries vary depending on the sociocultural context, residents' perceptions of the urban environment, and objective factors affecting the physical and mental health of the population.

Within the framework of this study, the focus was specifically placed on identifying the spatial characteristics that large-scale housing estates should possess to effectively withstand the most frequent and significant threats. Urban planning tools are not designed for emergency response; however, the spatial characteristics shaped before a critical situation can significantly influence the effectiveness of urgent managerial, social, and economic measures (Sharifi, 2019).

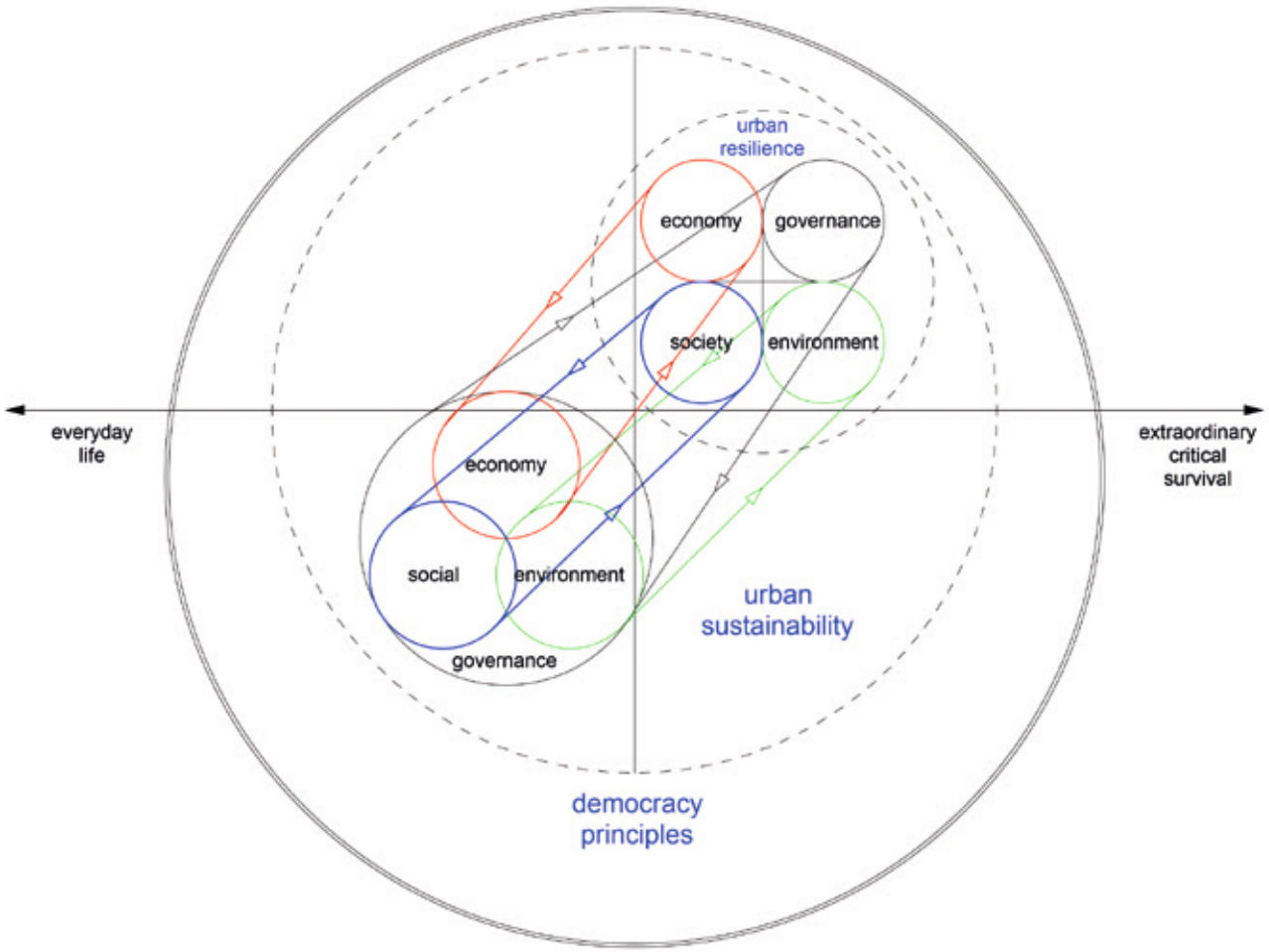

Fig. 3. *Urban resilience as a component of normal urban life within the value system of justice and democracy. Diagram by Nadiia Antonenko*

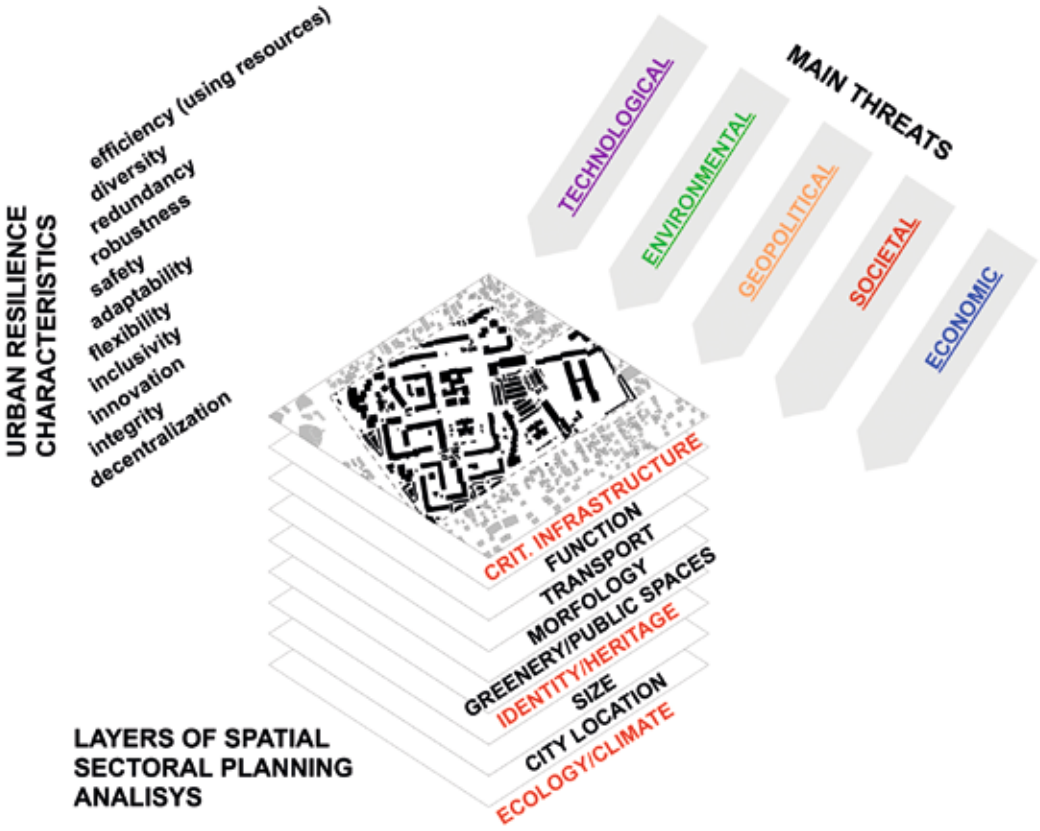

Fig. 4. Three-component model of spatial resilience of urban areas. Developed by Nadiia Antonenko

To identify the spatial characteristics of urban resilience within neighbourhoods of large-scale housing estates, a research model was developed, comprising three dimensions (Fig. 4):

- The types of threats that negatively affect the neighbourhood.
- spatial characteristics (considered primarily within the framework of standard sectoral planning analysis);
- urban resilience characteristics (neighbourhood as a resilient system).

The developed model is highly flexible: it allows for the adaptive inclusion or exclusion of specific characteristics within each of the three dimensions. This makes the model applicable not only to large-scale housing estates but also to other types of urban areas with varying spatial and social conditions.

The research was carried out in seven consecutive stages. To ensure objective data collection, the analysis was conducted step by step, with each new stage building upon the results obtained in the previous ones:

1) The first stage of the research aimed to identify the set of threats that evolved from the 1980s to 2024 in the context of residential neighbourhoods of the 1980s in Ukraine and East Germany, taking into account the specific socio-political and economic conditions. It also focused on determining the main spatial characteristics of these neighbourhoods, as originally planned and implemented, and on analysing the key spatial transformations that occurred between 1989/1991 and 2024, along with the underlying causes and nature of these changes.

2) The second stage of the study aimed to refine the set of key threats and determine the extent to which the original spatial characteristics of residential neighbourhoods have changed under their influence. All threats were classified into the following groups: technological, environmental, geopolitical, social, and economic. This approach aligns with the analysis of global risks presented in the World Economic Forum's Global Risks Report 2024 [World Economic Forum, 2024].

3) At the third stage, ideal spatial characteristics for neighbourhoods in large housing estates of the 1980s were de-

Fig. 5. *Studied neighbourhoods. Developed by Nadiia Antonenko*

veloped. To achieve this, sets of empirical spatial characteristics were formed within each layer of the sectoral spatial analysis.

4) The description of the ideal spatial characteristics of resilience formed the basis of the fourth stage of the study — a detailed layer-by-layer analysis of the spatial features of the selected neighbourhoods. For this research, " neighbourhoods" were defined as spatially similar urban structures bounded by major transport arteries (including public transport lines) or wide green corridors/linear public centres. To refine the results, an additional analysis was conducted based not on specific spatial parameters but on the urban resilience characteristics of the neighbourhoods, the set of which was determined based on previously published sources and researcher-developed lists related to the resilience of cities and resilient systems, taking into account the specific nature of the research subject.

5) As part of the fifth stage, a list of questions was developed to describe characteristics of urban resilience. This approach made it possible to assess not only the presence but also the quality of spatial resilience characteristics.

6) The sixth stage of the study involved a layered analysis of the urban resilience characteristics of each examined neighbourhood. For each layer of sectoral spatial analysis, the study assessed how the current urban resilience characteristics of neighbourhoods in Ukraine and Germany respond or could respond to various threats. Each such response was qualitatively evaluated, enabling the visualisation and interpretation of results: this made it possible to assess and compare the urban resilience of the selected neighbourhoods and to identify key vulnerabilities both within individual neighbourhoods and in the typical features of the corresponding development patterns in Ukraine and Germany. The results of the fourth and sixth stages complemented and refined each other, leading to more accurate and comprehensive findings.

7) The seventh stage of the study involved the development of possible spatial development scenarios and the sequence of their implementation. This work encompassed various scales of intervention: at the neighbourhood level, at the sub-neighbourhood level — including housing groups and individual buildings- and at the level of integrating the neighbourhood into larger systems, such as the district and the city.

The proposed methodology enables in-depth analysis of the spatial characteristics and transformations of neighbourhoods in large-scale housing estates, while also identifying vulnerabilities, assessing resilience to various threats, and shaping evidence-based future development scenarios. Its multi-level structure and integration of both quantitative and qualitative approaches make it a versatile tool for evaluating and designing sustainable and adaptive urban spaces.

Eight neighbourhoods were selected for analysis to represent typical large-scale housing estates of the 1980s in Ukraine and East Germany (Fig. 5). These include areas in the capital cities—Berlin and Kyiv—as well as in four major cities: Leipzig, Dresden, Kharkiv, and Odesa. Additionally, two estates from mid-sized, less affluent cities—Halle and Kherson—were included to broaden the socio-economic and spatial diversity of the sample (Table 1).

The selected neighbourhoods in Ukrainian and East German cities were chosen based on several key criteria, including variation in building density and location within distinct climatic and socio-economic contexts, which together ensure the representativeness of the comparative analysis:

- Cities with populations over 200,000. Such cities are characterised by diverse social and economic environments, making them particularly valuable for studying urban resilience.
- Planning and implementation period: late 1970s to 1980s. This period marked the final stage of mass housing construction in the former Soviet Union and Eastern Europe.
- Comparable neighbourhood size. The selected districts have similar building density and development area, allowing for a more precise comparison of their resilience and adaptive capacities, including ecological, social, and infrastructural aspects.
- Evidence of adaptation to changing conditions. This makes it possible to assess not only current resilience but also the effectiveness of responses to crisis events.
- Diverse forms of land use. Allows for evaluating the influence of different socio-economic groups—both owners and users—on the transformation of spatial characteristics within neighbourhoods.
- Varying degrees of exposure to security threats. An additional factor in the selection of neighbourhoods was the degree of threat from war. Ukrainian cities such as Kyiv, Kharkiv, Odesa, and Kherson are located in high-risk zones, which creates additional challenges for urban resilience, including infrastructure protection, civil defence systems, and emergency response. In contrast, East German cities such as Leipzig, Dresden, and Berlin are situated in stable and secure environments, allowing for a greater focus on more traditional aspects of urban resilience, such as ecological and social adaptation.

Name of neighbourhood	Description
Neighbourhoods No. 9/10, Vygurivshchyna-Troieshchyna large-scale housing estate, Kyiv	This neighbourhood is located in the central part of the Vygurivshchyna-Troieshchyna large housing estate in the Desnianskyi administrative district of Kyiv, in the northeastern part of the city. It borders the village of Troieshchyna to the west, Roman Shukhevych Avenue and the intersection of Bratislavska and Krajna Streets to the south, an industrial zone to the east, and fields beyond the village of Pohreby to the north. The neighbourhood is enclosed by Chervona Kalyna Avenue, Honoré de Balzac Street, Oleksandry Ekster Street, Serg Lyfar Street.
Vuzivsky neighbourhood, Tairova large-scale housing estate, Odesa	The neighbourhood is located in the Kyivskyi administrative district of the city. Tairova large-scale housing estate is primarily a high-rise residential area stretching from Inglezi Street and the 4th Station of Lustdorf Road in the north to Arkhitektorska Street in the south. To the east, the neighbourhood borders the low-rise cottage developments of Dmytrivka and Bolshoy Fontan, while the western boundary also marks the city's edge. The borders of Vuzivsky Neighbourhood are defined by Lustdorf Road, Oleksandr Nevskyi Street, Shyshkin Street, and Chernihivska Street.
Neighbourhood No. 1, Tavriiskyi large-scale housing estate, Kherson	This neighbourhood, located in the northwestern part of Kherson, on the right bank of the Dnipro River, the Tavriiskyi large-scale housing estate belongs to the Suvorovskyi administrative district. The boundaries of neighbourhood No. 1 are defined by the 200th Anniversary of Kherson Avenue, Pokrysheva Street, Karbysheva Street, and 49th Guards Division Street.
Neighbourhood No. 2, Northern Saltivka large-scale housing estate, Kharkiv	This neighbourhood is located in the northeastern part of Kharkiv. The area falls within the Kyivskyi and Saltivskyi administrative districts. It borders neighbourhoods No. 524 and No. 531 to the south, the neighbourhoods of Velyka Danylivka and Internatsionalistiv to the west and northwest, and the Ring Road to the north and east. The boundaries of Neighbourhood No. 2 are defined by Lesi Serdiuk Street, Druzhby Narodiv Street, Hvardiitsiv Shyronintsiv Street, and Metrobudivnykiv Street.
Eastern neighbourhood in Hellersdorf Promenade, Berlin	The neighbourhood is located in the Marzahn-Hellersdorf district. To the north, it borders the administrative boundary of Berlin; to the south, it borders the Hellersdorf centre. A large green area lies to the west, while the eastern boundary is formed by another part of the Hellersdorf Promenade. The neighbourhood is enclosed by Landsberger Straße, Stendaler Straße, Janusz-Korczak-Straße, and Zerbststraße.
Western neighbourhood in Paunsdorf, Leipzig	The neighbourhood is located on the eastern outskirts of Leipzig and constitutes the western part of the Paunsdorf district. It borders the green area of Grüner Bogen to the north, and is surrounded by low-rise residential developments and green spaces to the south, west, and east. The boundaries of the neighbourhood are defined by the streets Heiterblickallee, Geißblattstraße, Waldkirchstraße, and Permoserstraße.
North-Eastern neighbourhood in Neu-Gorbitz, Dresden	The neighbourhood is separated from the highway by a green belt park, interspersed with low-rise development. To the south, it borders another North-Eastern neighbourhood in Neu-Gorbitz, while to the west and east, it is surrounded by public green spaces with elements of low-rise buildings. The boundaries are defined by Hohenpromenade, Leutewitzer Ring, and Julius-Faltin-Straße.
Residential Complex No. 1/4 in Silberhöhe, Halle	The neighbourhood is located in the southern part of Halle and includes two residential complexes — WK1 and WK4. To the north, it is separated from the highway by a green buffer strip; to the south and east, it borders a public green centre; and to the west, it adjoins a large sports zone and low-rise residential buildings. Boundaries: Freiburger Straße, Gustav-Staude-Straße, Ludwig-Bethke-Straße.

Table 1. Neighbourhoods for analysis

This comparative approach allowed for the identification of both shared trends and unique strategies that enhance urban resilience and adaptability. The study highlights how both formalised and spontaneous responses contribute to strengthening urban resilience and identifies solutions with potential for broader application. These insights form a basis for developing future framework scenarios to improve urban resilience in both Ukraine and Germany.

5 Key components of spatial urban resilience in large-scale housing estates

In the context of modern urban development, the issue of objectively assessing urban resilience is becoming increasingly relevant. Several internationally developed and tested metrics and indices already exist to provide a comprehensive diagnosis of cities' resilience to risks, including climate, infrastructure, social, and governance challenges. These systems serve both as monitoring tools and as a foundation for developing strategies for sustainable development, disaster risk mitigation, and enhancing the adaptive capacity of urban areas.

One of the most comprehensive and structured systems is the City Resilience Index (CRI) (Arup, 2019; Rockefeller Foundation, n.d.), developed by the Rockefeller Foundation and the consulting firm Arup. The index covers four key domains: health and well-being, economy and society, infrastructure and ecosystems, and leadership and strategy. Each domain is broken down into a set of indicators, ranging from assessments of access to healthcare and housing conditions to infrastructure resilience, mechanisms for public participation, quality of local governance, and effectiveness of ecosystem services. Another important assessment system is the Disaster Resilience Scorecard for Cities, developed under the UNDRR initiative (UNDRR, 2017) and based on the principles of the Sendai Framework for Disaster Risk Reduction (UNDRR, 2015). This tool focuses on disaster risk management and analyses parameters such as mortality rates, the number of affected individuals, economic losses, and the city's capacity to restore infrastructure and services. Special attention is paid to the presence and effectiveness of risk reduction strategies, early warning systems, and international cooperation.

At the level of technical regulation, the international standard ISO 37123:2019 (ISO, 2019) is in force, offering a comprehensive list of resilience indicators for cities. These include economic diversification, energy efficiency, literacy rates, access to healthcare, budget transparency, climate adaptation mechanisms, and much more. The OECD Resilient Cities Framework provides a conceptual foundation for assessing resilience through the lens of four interconnected components: economic sustainability, social inclusiveness, environmental responsibility, and institutional quality of governance (OECD, 2016). From an environmental perspective, the Environmental Performance Index (EPI) is widely used to evaluate the effectiveness of urban environmental policies (Yale Centre for Environmental Law & Policy, 2022).

A major limitation of existing assessment systems lies in their broad focus on social, governance, and environmental aspects. As a result, the quality and performance of specific spatial characteristics are insufficiently addressed, complicating decisions on spatial interventions and urban transformation.

The core methodological challenge in developing urban resilience indices is balancing between excessive specificity and overgeneralization. Narrowly focused indices (e.g., for street network resilience or climate adaptability of green spaces) make it difficult to inform holistic decisions (Pimm, Raven & Peterson, 2014; Cutter, Ash & Emrich, 2015). Conversely, overly broad indices tend to obscure critical spatial parameters essential for practical design solutions (Khazai, 2015). Thus, the key is achieving a balance between universality and sensitivity to local conditions—an issue central to understanding the multi-component nature of urban resilience (Sharifi & Yamagata, 2016).

In this study, the selection of resilience characteristics for analysing residential neighbourhoods was driven by the need to ensure the resilience and adaptability of the spa-

tial-morphological features of high-density large-scale housing estates built in the 1980s in Ukraine and East Germany. These characteristics were examined through the lens of their capacity to enhance the resilience of urban systems to potential threats and to support recovery both in the short term—following crises—and in the long term—by contributing to sustainable development and improved quality of life in these areas, in line with contemporary views on sustainable urban development.

Resilience characteristic	Description
Efficiency	The ability to efficiently utilise available resources is a crucial aspect of resilience. For the large-scale housing estates from the 1980s under analysis, this parameter is particularly important, as many of these areas are characterised by outdated infrastructure systems that require optimisation and upgrades to improve energy efficiency and reduce costs. Efficient resource use becomes a key factor in ensuring the resilience and long-term viability of such neighbourhoods amid economic instability and limited resources.
Diversity	Access to resources with diverse properties and characteristics is another key aspect. Large-scale housing estates built during the 1980s often face issues of uniformity and monotony in their urban structure. The diversification of spatial and social elements in these areas enhances their ability to adapt to a variety of external influences, strengthens social resilience, and reduces the risks of residential environment degradation.
Redundancy	The availability of redundant resources is essential for ensuring resilience in times of crisis or unexpected change, such as natural disasters or economic shocks. Redundant resources—including alternative communication routes, additional spaces for accommodation, and backup life-support systems—are necessary to maintain the functionality of such neighbourhoods under stress.
Robustness	The ability to retain core characteristics under external stress is critical for resilience. For the large-scale housing estates from the 1980s, this parameter is especially important, as these areas often face issues related to durability and may be vulnerable to physical deterioration or structural damage. Maintaining the integrity and functionality of these complexes requires infrastructure robustness capable of withstanding both extreme weather conditions and age-related degradation.
Safety	The ability to provide safe conditions under threat is a vital component of resilience. Given the age of many buildings in these neighbourhoods, resident safety is a key concern. This includes both physical safety—from fires, flooding, and other emergencies—and social safety, which is especially important for elderly residents and other vulnerable groups.
Adaptability	The ability to adapt and transform to enhance resilience is increasingly crucial in the context of changing social structures, technologies, and climate conditions. For 1980s-era large-scale housing estates, adaptability has become a key factor. For example, reconfiguring residential blocks for more flexible use, such as offices, cultural centres or other community needs, or modernising infrastructure to meet current demands, contributes to improving the longevity and functionality of these areas.
Flexibility	The ability to rapidly adapt to threats is crucial in the context of quick responses to dangers such as natural disasters or economic crises. This also involves changing the functions of spaces when necessary.
Inclusivity	The ability to protect the most vulnerable populations is a critical factor in analysing large-scale housing estates from the 1980s, where many areas may be marginalised. It is important to consider the needs of vulnerable groups, such as the elderly, people with disabilities, and low-income families. The resilience of such neighbourhoods requires creating equal opportunities for all residents, including protecting their interests and improving access to essential resources.

Resilience characteristic	Description
Innovation	The use of innovative approaches is essential in the context of ageing infrastructure and increasing external threats. Innovative solutions (e.g., the implementation of smart technologies, energy-efficient materials, and systems) can significantly improve the quality of life and enhance the resilience of these large-scale housing estates to future challenges.
Integrity	The availability of external resources capable of compensating for internal shortages is an important characteristic. This property relates to the ability to integrate external resources (e.g., when additional financial or material support is needed, especially in crises). For instance, collaborating with neighbouring districts or municipal authorities to address infrastructure issues can become a crucial factor in ensuring resilience.
Decentralization	The ability to maintain resilience and function even if the system loses central nodes or resources is an important quality for enhancing the flexibility and self-sufficiency of neighbourhoods since the 1980s. Implementing decentralised solutions for managing energy supply, water supply, and other vital functions helps improve their resilience in the event of external shocks or crises.

Table 2. Resilience characteristics of a large-scale housing estate

The methodology for assessing urban resilience within the analysis of spatiality in a specific neighbourhood was based on a comprehensive approach to identifying spatial characteristics and their resilience to various types of threats. The development of threshold values for each spatial characteristic is a key step in assessing the resilience of urban areas. First, such values allow for translating abstract principles of sustainability and adaptability into specific, measurable parameters applicable to spatial layers of urban analysis. Second, they provide a toolset for comparing and monitoring existing neighbourhoods, as well as for identifying vulnerabilities and the potential for spatial transformation. Third, the existence of threshold values facilitates the creation of design guidelines, enabling architects and urban planners to develop solutions that inherently include the principles of resilience and urban sustainability.

Specific spatial parameters defined as sufficient for ensuring basic urban resilience can later form the basis for developing specialised indices. Such indices allow for a more precise and context-sensitive evaluation of urban areas, taking into account their morphological, functional, infrastructural, and sociocultural characteristics. They can also be adapted to different scales, ranging from a neighbourhood to the entire city, providing flexibility in their application (Burton, 2015).

Below are the threshold values for spatial characteristics of resilience that were adopted in the context of the analysis of neighbourhoods built in the 1980s in the cities of Ukraine and East Germany.

Spatial Layer "Size"

The size of a city plays a key role in its resilience, influencing infrastructure management, threat response, and social structure. Large cities have more developed networks, which accelerate crisis response, but they also increase coordination complexity and vulnerability to failures. Smaller areas may be more vulnerable to environmental risks, such as flooding, due to limited protective mechanisms, while larger cities can implement more extensive solutions. Size also affects the ability to undergo social changes: in small cities, changes happen more quickly, but in larger ones, they tend to be more significant, though more complicated due to the diverse range of interests.

Criteria	Value/Description
Total area of the neighbourhood	The length of the neighbourhood perimeter walk does not take more than 30-40 minutes – up to 3 km, neighbourhood area – up to 50 hectares; ensures compactness, which is critical for mobility, resource accessibility, and emergency evacuation
Current plot ratio	0.20; indicates a moderate density of buildings, allowing for a balance between built and open spaces, which is essential for adapting to climate, sanitary, and infrastructure risks
Estimated number of inhabitants	The number of people must be effective for evacuation (small enough), and effective for economic activity (large enough) – 5000 – 15000; on one hand, it is a sufficiently compact community for effective logistics and social support; on the other hand, it provides enough residents for sustainable economic and social exchange
Current population density	10000–30000 people/km²; reflects a critically important balance: a high density ensures the viability of public spaces and services, but does not exceed the threshold where infrastructure pressure increases, making the area more vulnerable to threats

Table 3. Ideal characteristics of spatial layer "Size"

Spatial Layer "City Location"

This layer plays a key role in ensuring the resilience of a residential neighbourhood both in everyday and crisis conditions. Its importance is linked to the ability for quick and safe evacuation, transport connectivity, accessibility to critical infrastructure, as well as environmental sustainability.

Criteria	Value/Description
City location	peripheral location of the neighbourhood about the city border (taking into account the rose of war /source of natural disaster); spatial possibility of quickly organizing temporary safe pedestrian routes into the center up to 2 km long with full inclusion of the main pedestrian routes; underground transport connection between the neighbourhood and the city; availability of evacuation routes from the neighbourhood - at least 4
Distance to city centre	adjacency or location in the city center and the possibility of spatial organization of a safe path to the city center - underground accessibility to the city center, distance up to 2 km (30 minutes on foot); determines strategic connectivity: such proximity ensures access to essential resources, medical institutions, administrative structures, and coordination capabilities in case of a crisis
Distance to housing estate centre/sub-centre	adjacency or location in the district sub-center and the possibility of spatially organizing a safe path to the district center - underground accessibility to the district center, distance up to 1 km (15 minutes on foot); critical for everyday resilience: it ensures access to local functions — schools, shops, first aid points, and public spaces.
Distance to the nearest intercity and international transport station	the presence of an intercity terminal/station directly within the neighbourhood or adjacent to it (presence of a transport park) or the presence of an underground transport connection in the neighbourhood with city intercity terminals/stations; at least 3 intercity transport facilities within walking distance - up to 2 km (30 minutes); 2 types of intercity transport. This is especially important in the context of mass evacuations, resource delivery, and post-crisis recovery.

Criteria	Value/Description
Distances to the main park/ recreational green zones	direct adjacency of the neighbourhood to (at least one) green recreational zone - up to 0 km; absence of threats to the development of green areas (in particular, green corridors); presence of public functions/zones along green corridors (absence of "places of fear"); the presence of plants that do not require constant care and seeding
Presence of pollution objects nearby	There are no pollution objects (industrial facilities), the distance to the nearest one is more than 3 km; minimises long-term environmental and sanitary risks, helping to preserve the physical health of residents and the overall environmental resilience of the district.

Table 4. Ideal characteristics of the spatial layer "City Location"

Spatial Layer "Morphology"

Urban morphology plays a crucial role in city resilience, influencing the physical robustness of the built environment, its adaptability, and flexibility of use. Building density, street configuration, and the distribution of open spaces determine how effectively a city can cope with external threats and recover quickly from crises. A well-planned urban structure enhances mobility, access to resources, and post-disaster recovery. Moreover, morphology contributes to inclusivity: cities with diverse development patterns provide accessibility for various population groups and create opportunities for housing, business, and public services.

Criteria	Value/Description
New construction (after 1990), % densification	from 20% - presence of new public buildings and housing of a different typology; reflects the integration of contemporary architectural solutions, new public functions, and residential facilities. This strengthens the diversity of the urban environment and enhances its adaptive capacity. Such interventions can improve the quality of the urban fabric without compromising connectivity and identity.
New construction (after 1990), % extension	0% (comprehensive reconstruction only); highlights a strategy focused on working within existing boundaries, preventing fragmentation and inefficient land use. This is vital for resilience, especially in the context of limited resources and the risk of uncontrolled growth.
New construction (after 1990), % temporary	0%, except for temporary housing or temporary tactical urbanism facilities, except for critically necessary ones and tactical urbanism projects, reduces the risks of spontaneous, low-resilience construction that may become unsafe in a crisis
Modernised buildings, energy efficiency improvement	100% of buildings are in good technical condition, renovated, insulated, adapted to the needs of residents (including inclusion measures), use of re-used construction technologies, buildings adapted to the needs of vulnerable categories of residents indicates a high level of resilience to energy and climate threats, as well as environmental inclusiveness. This ensures physical durability, energy savings, and living comfort for all population groups
Chaotic private initiative modernisation	0%, except for temporary housing or temporary, tactical urbanism facilities; reduces spatial fragmentation and supports the preservation of architectural order and safety. This is important for the coherence and coordination of adaptation efforts.
Unmodernized buildings	0%; the entire housing stock meets modern standards, significantly reducing the area's vulnerability.
Demolished/ Ruined buildings	up to 5%, the presence of ruined/destroyed buildings is ineffective, but the places in their place can be used as vacant territories (to enable spatial response during a threat). This is an element of redundancy and response flexibility

Criteria	Value/Description
Building height	less than 5 floors with the possibility of quick evacuation from the upper floors, taking into account the needs of vulnerable categories of residents; ensures a high level of evacuation safety, particularly for vulnerable population groups, and supports faster recovery after destruction
Building density	approximately 1.00; indicates a balanced urban structure that ensures both the intensity of land use and a comfortable, livable environment
Morphological diversity of buildings	availability of different types of buildings, inclusion of individual projects, characterised by varied typologies and individual architectural designs, enhances the adaptability and resilience of the environment, supporting both functional and social diversity

Table 5 Ideal characteristics of spatial layer "Morphology"

Spatial Layer "Mobility"

Mobility is a key component of urban resilience, as it ensures physical connectivity, accessibility, and the capacity for rapid response under various threat conditions. Well-developed transportation infrastructure and communication systems play a crucial role in enhancing the city's flexibility, enabling the swift mobilisation of resources and the evacuation of populations in the event of disasters.

Spatial mobility also significantly affects the city's ability to recover after crises by facilitating the efficient movement of emergency services and recovery materials. Moreover, mobility is directly linked to accessibility for different population groups. A city with a well-connected transportation network and access to diverse areas guarantees equitable access to essential resources and services, thereby enhancing social resilience and inclusiveness.

Criteria	Value/Description
Presence of transport connections with other areas of the city	the number of vehicles is optimized and centralized, different types (gasoline, gas, electricity, biofuel) + there is a variety of means of evacuation, including commercialized types available, including for people with physical, mental, economic vulnerability - at least 4 types of transport (pedestrian, private car, one of the modes of public transport + some one); Mandatory operation of underground transport; Possibility of rapid commercialization of transport; if necessary, transport city resources can be transferred from other areas – for example, during a total evacuation. Fosters spatial integration and supports both everyday and emergency mobility.
Accessibility of public transport stops	50 m to the nearest transport stops in the form of mobile shelters (if there are no other accessible shelters) - you can walk to the underground public transport station; ensures the possibility of safe and rapid movement even under crisis conditions, thus increasing the resilience and safety of transport infrastructure.
Accessibility of the car parking lot	up to 50 meters for each car owner/more than 2 parking options + rental cars options; with at least two options, enables residents to choose optimal mobility scenarios and enhances the functional flexibility of the environment. This becomes critically important in cases of transport overload, accidents, or evacuation needs.
Accessibility of bicycle parking lot	up to 50 meters for each bike owner/more than 2 parking options + rental bicycles/electric scooters options - you can get to the underground public transport station
Barrier of pedestrian paths	a barrier-free neighbourhood environment; enhances inclusivity and accessibility for all population groups, including those with limited mobility, making everyday mobility more resilient and less dependent on external conditions.

Criteria	Value/Description
Emergency transport access	No access barriers, presence of a fire station/ambulance station in the neighbourhood or in the surrounding area, is a mandatory requirement to ensure life safety and rapid response during disasters.
Digitalisation of transport	The transport system is digitalised, but it can work without digitalisation; it increases its efficiency and manageability under normal conditions and guarantees resilience in the face of power outages or cyber threats.

Table 6. Ideal characteristics of spatial layer "Mobility"

Spatial Layer "Function"

The layer is a key element of urban resilience, as it reflects a neighbourhood's ability to maintain its essential functions under various threats, and to interact effectively under stress. A flexible and accessible functional structure enables the rapid reconfiguration of systems to meet emerging needs during a crisis. Functional resilience is directly linked to social resilience, as the availability and operability of essential services help strengthen public trust and social cohesion in times of crisis.

Criteria	Value/Description
Housing function	social municipal housing, which is managed centrally, is at least 70%, and the availability of technologies for temporary decentralised provision of water, heat, electricity, communications; it is possible to organise the automation of data collection and processing for the operation of houses and local areas
Sale of essential goods	there is a market point, or a place where regular fairs are held (the possibility of implementing spontaneous trade in the event of a threat); large shopping center – up to 2 km; supermarkets/primary goods stores (chain commercial enterprises) – within 50 m; pharmacies – within 50 m; gas stations and car services (network commercial enterprises) – at least 2 at a distance of up to 1 km; there are care services for vulnerable categories of residents (if there is a threat, they can be expanded – there are vacant premises, municipal services or network commercial enterprises); retail outlets/machines are selling essential goods without staff/partially without staff; routes to these functions are inclusive; guarantees access to vital resources.
Providing services	1 service facility per 5 hectares (preferably network enterprises); crucial for maintaining mobility and evacuation capacity when necessary.
Medical infrastructure	medical facility within the neighbourhood (up to 0.3 km) – up 2 object with underground shelter (municipal or state subordination; commercial restrictions are excused); hospital – up to 3 km (municipal or sovereign subordination); availability of technologies for temporary decentralized provision of water, heat, electricity, communications; availability of mobile mobile medical services. Temporary provision technologies for water, heat, and communication for medical facilities are essential in crisis conditions to ensure their autonomous operation.

Criteria	Value/Description
Sociocultural infrastructure	the presence of a club institution/library/temple (in believing communities) – from 2 object with underground shelter; educational institution (secondary technical, higher, for adults) – from 2 object; a sufficient number of places in kindergartens and schools, which have additional functions during non-school hours, there is an area for placing temporary modular mobile classrooms next to the main buildings; availability of vacant territories and premises for temporary, regime or permanent placement of socio-cultural infrastructure facilities; tactical urbanism/living laboratories – spatial monitoring of the current needs of residents; the main approaches to buildings and internal space meet the requirements of inclusivity; availability of technologies for temporary decentralized provision of water, heat, electricity, communications
Area of the functional neighbourhood centre	5% of the neighbourhood territory - multicultural centre (combination of at least 3 main functions); availability of technologies for temporary decentralised provision of water, heat, electricity, communications. These centres should be located within walking distance and ensure access to core services, including healthcare and social support, while offering convenient integration with the neighbourhood's critical infrastructure.
Sports infrastructure	presence of a stadium with some workout equipment, some functions are temporarily located in shelters (the main approaches to buildings and the internal space meet the requirements of inclusivity). Sports facilities can be repurposed as shelters or gathering centres during crises.
Office buildings and production	from 2 institutions (within a radius of 1 km); there are inclusive routes, the main approaches to buildings and the internal space meet the requirements of inclusiveness; possibility of placing enterprises/offices within a radius of 1 km in empty buildings, vacant territories, underground spaces
Administrative institutions	from 2 institutions (within a radius of 1 km), there is the possibility of local coordination of selforganization in the event of a threat; availability of technologies for temporary decentralized provision of water, heat, electricity, communications; the main approaches to buildings and internal space meet the requirements of inclusivity; the possibility of organizing automation of data collection and processing according to the competencies of residents in the event of a threat contributes to functional resilience.
Buildings without function/ruined	some vacant buildings or premises are empty or have temporary functions – at least 2 objects; it is possible to organize automation of data collection and processing if it is necessary to place a particular function in vacant premises/spaces; availability of technologies for temporary decentralized provision of water, heat, electricity, communications; premises in municipal property capable of coordinating actions at the neighbourhood level in the event of a threat is also crucial.
Shelters	available within a radius of 50 meters, access from residential buildings, public buildings, public spaces, there are internal connections, transitions between shelters; the presence of ground mobile shelters; the main approaches to the shelters and the internal space meet the requirements of inclusivity; it is possible to organize secure access; availability of technologies for temporary decentralized provision of water, heat, electricity, communications can be used to deploy additional functions, such as emergency shelters or evacuation points, significantly increases a neighbourhood's flexibility. These facilities should be conveniently located and meet inclusivity standards, ensuring safe conditions for all population groups, including vulnerable individuals.

Table 7. Ideal characteristics of spatial layer "Function"

Spatial Layer "Greenery / Public Spaces"

Green spaces and public areas play a vital role in enhancing the resilience of urban territories from both environmental and social perspectives. They contribute to maintaining ecological balance, improving air quality, and reducing noise pollution. These areas function as natural buffers against climate-related threats, support biodiversity, and improve the urban microclimate. Public spaces are the foundation of social resilience, providing residents with places for relaxation, social interaction, and cultural activities. In times of crisis, they help reduce psychological stress and serve as sites for community recovery. Moreover, green areas can be adapted for emergency use, such as hosting temporary shelters or mobile medical units.

Criteria	Value/Description
Connecting green spaces with city/district green infrastructure	connection with citywide green infrastructure and with external green areas – emphasis on biodiversity and vegetation health; the ability of vegetation to self-preserve and self-regenerate without human help; absence of "places of fear"; automatic watering technologies, maintaining soil moisture; inclusiveness of the main pedestrian routes of the green frame
Connecting neighbourhood green spaces	continuous green neighbourhood frame – emphasis on biodiversity and vegetation health; the ability of vegetation to self-preserve and self-regenerate without human help; automatic watering technologies, maintaining soil moisture; absence of "places of fear"; inclusiveness of the main pedestrian routes of the green frame
Area of greenery in public spaces	inner yard greenery – 25-30 %; inner alleys greenery – 15-30 %; greenery of alleys along highways – 10-15 %; neighbourhood parks/square – 10-12 %; the possibility of allocating free territory for emergency needs (the advantage of decentralized/mobile critical infrastructure facilities or temporary functional essential facilities) – 2-5 %
Functional content of the greenery spaces	meet the needs of at least eight main social groups – preschool children, primary school children, teenagers, single residents and couples, families with children, elderly residents, people with disabilities, residents with animals, residents with financial problems; there is regular monitoring of the social composition of users of public spaces and the territory has the opportunity to transform; automatic watering technologies, maintaining soil moisture; public spaces are attractive to residents of neighboring areas
Inclusiveness in green public spaces	Complete inclusiveness; designated for the critical mobile infrastructure in case of emergency; meets the needs of diverse social groups; offering universal accessibility.
Territory grooming	good condition and care of plants; the ability of vegetation to self-preserve and self-regenerate without human help; control of invasive plant allergens; the possibility of active participation of residents in caring for plants: the presence of urban vegetable gardens/front gardens; automatic watering technologies, maintaining soil moisture; active involvement of residents in gardening and urban agriculture (e. g., community gardens and front yards) further strengthens the bond between communities and their environment.
Closed, inaccessible territories	up to 10 % (mainly kindergartens, service areas of supermarkets); areas with direct access to natural zones should be available for multipurpose use, depending on the nature of the threat. These natural spaces offer flexibility for emergency adaptation.
Land stocks nearby	There is direct contact with the natural area, which can serve different functional purposes (depending on the type of constant threat)
Form of ownership	not less than 80 % – municipal property; to ensure long-term resilience, allowing local governments to maintain and manage green areas efficiently and to respond swiftly to changing conditions.
Average size of yards	0.5-0.7 ha, mostly semi-closed perimeter with the possibility of restricting entry to outsiders (day/ night modes); to allow for controlled nighttime access and to enhance resident safety

Table 8. Ideal characteristics of spatial layer "Greenery / Public Spaces"

Spatial Layer "Climate Adaptation"

The layer plays a key role in ensuring the resilience of urban areas to climate change and extreme weather events. It encompasses a wide range of strategies aimed at reducing the impact of climate-related risks such as rising temperatures, floods, droughts, and severe storms. Key aspects include the development of resilient infrastructure, the use of nature-based solutions, and biotechnologies. Climate adaptation also involves increasing the energy efficiency of buildings, improving thermal insulation, and using renewable energy sources. These measures help mitigate not only the physical impacts of climate change but also its social effects, enhancing the quality of the urban environment and the level of public safety.

Criteria	Value/Description
Topographical features	slope between 1 – 4.8 degrees, is not a low-lying area compared to adjacent neighbourhoods; developed underground storm drainage system with possible reuse of rainwater (for example, for irrigation) Presence of overheating zones – absent
Availability of water bodies, small objects (springs, lakes, small rivers)	presence of underground springs, wells, walking distance – up to 1 km.
Availability of water bodies, large objects (rivers, seas)	from 1.5 km, helps reduce thermal stress on both the population and the environment, an especially relevant measure in the context of global temperature rise
Height above sea level	from 5 m
Presence of natural disasters	Consequences are reversible in a short period, and do not have a significant impact on the spatial characteristics of the neighbourhood and adjacent neighbourhoods
Natural ventilation	There are no unventilated zones or heavily ventilated zones; this ensures more uniform air circulation and prevents stagnant conditions that can compromise livability.
Coatings	water-absorbing and water-retaining coatings predominate
Albedo	predominantly white and light-colored buildings; automatic irrigation zones, water objects – their presence helps reduce the urban heat island effect by maintaining cooler ambient temperatures
Green roofs or green walls	presence predominates; integrate vegetation for natural temperature regulation, enhance the urban ecosystem and improve a city's overall climate resilience.

Table 9. Ideal characteristics of the spatial layer "Climate Adaptation"

Spatial Layer "Critical Infrastructure"

Critical infrastructure forms the foundation of resilience for cities and neighbourhoods against various threats. This spatial layer includes key elements such as energy supply, water provision, heating, and communication systems—everything necessary for the continuous and effective functioning of urban life under any circumstances. The reliability and robustness of these systems are essential for maintaining the viability of residential areas. Effective critical infrastructure minimises damage and ensures the uninterrupted delivery of vital services to the population.

Criteria	Value/Description
Electricity	centralised, but with many low-power substations, there are decentralised autonomous sources of electricity; this configuration allows for flexible energy distribution and ensures continued system operation in the event of disruptions.
Internet	cable Internet and access to satellite Internet, ensuring protective measures for cybersecurity
Water supply and drainage	centralised supply, availability of emergency water reservoirs in case of threat/availability of local treatment systems; a loop water system; a circular water supply system ensures water availability in any condition, while measures for local rainwater absorption help prevent flooding and support effective water resource management.
Gas supply	centralised, but use of domestic gas is minimised; outdoor cooking areas (barbecue)
Heating	combined, there is access to centralised, but mostly decentralised; use of different heating technologies; while centralised heating must be provided, most users should also have access to decentralised systems, such as individual boilers, to maintain flexibility during disruptions.
Radio point	citywide or national broadcasting, in working condition
Availability and quality of grey infrastructure	citywide system, in working condition, collecting rainwater for reuse; measures for local absorption of rainwater by the surface of the earth are widely developed
Roof area for solar collectors	from 70% of „area of residential buildings"; significantly decreases reliance on centralised energy systems and supports cost savings in heating and hot water provision
Public warning system	Citywide system, in working condition; must be in place to deliver timely and essential information to residents about potential threats and recommended safety measures.

Table 10. Ideal characteristics of the spatial layer "Critical Infrastructure"

Spatial Layer "Identity"

The spatial layer "identity" is important because it reflects the connection between historical heritage, cultural characteristics, and the contemporary needs of residents. Preserving and developing the identity of a neighbourhood contributes to strengthening social cohesion and creating a positive image of the area. This layer helps integrate new and old elements of the urban environment, creating conditions for sustainable and harmonious development.

It is important to emphasise that the proposed framework values and parameters can be refined and adjusted in the future during practical implementations and continuous monitoring. However, fixing these specific values at this stage is an important step, as it allows for a more precise understanding of the spatial characteristics within the framework of the multifaceted and multidimensional concept of urban resilience. This process lays the foundation for developing more accurate and adaptive resilience indices that can effectively reflect the actual conditions and needs of the city, ensuring its development with long-term safety and quality of life in mind.

Criteria	Value/Description
Signs of preservation of the original spatial structure	planning frame preserved, taking into account changes in the current citywide concept of integrated development; despite urban changes, the basic structure of the neighbourhood and its functional zones remain identifiable, and transformations occur within the broader urban context, supporting a connection with historical heritage and the unique identity of the area.
Degree of conservation of morphological features of buildings	Signs of compliance with the current needs of residents; preserved, as evidenced by the fact that architectural objects are adapted to modern residents' needs. This includes not only the use of contemporary construction technologies and materials but also the consideration of functional requirements. Buildings maintain their historical and cultural value while providing comfortable living conditions and meeting current safety and energy efficiency standards.
The degree of conservation of green public spaces	green frame, was preserved, strengthened, and included in the citywide green frame
Degree of preservation of specific decorative elements/monumental objects	and typical for the place elements and objects of monumental art have been preserved; these elements often hold cultural and historical significance, and their preservation helps maintain the identity of the neighbourhood, supporting continuity between the past and the present.
Signs of the formation of a new identity	signs of compliance with the current needs of residents, defined by its alignment with the current needs of the residents. Signs of the development of a new identity can be observed in the renovation of public spaces and the introduction of new infrastructure elements that reflect the neighbourhood's desire to be more modern, accessible, and inclusive for all social groups.
Level of external stigmatisation	absent, work with residents of neighbouring areas to form a positive image. Cooperation with neighbouring districts and active participation of residents in the transformation process help form a positive image of the neighbourhood, improving its perception both inside and outside the area.
Social basis for the formation of a new identity	the presence of a permanent connection to the neighbourhood, the opportunity to constantly work with residents of the area, identifying current needs, and the adaptation of infrastructure and public spaces according to current requirements.

Table 11. Ideal characteristics of spatial layer "Identity"

6 Spatial urban resilience of large-scale housing estates in Ukraine

Comparing neighbourhoods situated in different cities and countries enables the identification of key characteristics that make an area more or less resilient to external and internal threats. Such comparisons help not only to reveal common trends but also to analyse which specific elements contribute to resilience in the face of various challenges, such as natural disasters, social crises, or economic shocks.

Approaches to urban planning and neighbourhood-level governance in Ukraine and Eastern Germany differ significantly, due to distinct historical, social, and economic contexts. Since the 1990s, Germany has emphasised comprehensive, high-tech solutions and the integration of sustainable technologies into daily life. In contrast, urban resilience in Ukraine has typically evolved more organically, often as a direct response to pressing challenges, particularly those related to war, prospects for post-war recovery, the need for restoration and reconstruction of critical infrastructure, and the closure of urban gaps, frequently in the context of limited financial resources.

Today, large-scale housing estates in Ukraine are under simultaneous pressure from multiple powerful and interconnected global threats, the most critical of which remains the full-scale war. The military threat is the most immediate and devastating. It not only directly impacts the physical living environment—damaging residential buildings, engineering networks, and transportation infrastructure—but also triggers cascading effects across all other urban systems. We are witnessing a unique and tragic collapse of urban resilience—a so-called "domino effect" (Wamsler, 2015), in which already unbalanced and vulnerable urban life-support systems rapidly deteriorate under the weight of a single, dominant trigger: war. The conflict initiates a chain of secondary crises, exacerbating pre-existing climate, social, and economic challenges. Collectively, these pressures overwhelm urban systems, making large-scale transformation and financial support essential for recovery.

Shelling, attacks on critical infrastructure, and civilian casualties have led to the destabilisation and depopulation of entire large-scale urban housing estates, particularly those near the front lines. Residents are forced to abandon their homes, logistics chains are disrupted, and access to basic services disappears. Electricity, communication, heating, and water supply become unreliable or cease to function altogether. Even cities located far from the front experience high levels of vulnerability, undermining the potential for resilient planning, investment, and systematic urban development.

Climate-related threats, which under normal circumstances would require a strategic and systemic response, are further intensified by the war. Climate deterioration is reflected in rising summer temperatures, more frequent weather anomalies, declining air quality, and diminishing water resources. In wartime conditions, addressing these challenges becomes nearly impossible. Green spaces are destroyed by shelling, fires, or simply degrade due to a lack of maintenance. Funding for environmental programs is halted or diverted to military needs. The abandonment of investments in renewable energy becomes an economically rational decision under the persistent threat of destruction. A vicious cycle emerges, worsening environmental conditions harm public health, while the lack of green infrastructure restoration renders districts even more vulnerable to extreme climate events (Otto et al., 2025).

Social threats have also reached new levels of intensity and scale. Poverty rates are rising sharply, incomes are falling, and the labour market is contracting. Many residents are losing their jobs, particularly in sectors dependent on stability and consumer demand. Businesses are closing, and new enterprises are rarely established due to risks, uncertainty, and a lack of capital. Social stratification is deepening: the gap between vulnerable groups and more resilient segments of the population is widening. Distrust,

frustration, and polarisation erode social capital and the potential for horizontal self-organisation.

The share of elderly individuals and people with disabilities—groups requiring additional support —is increasing, and existing systems are unable to meet their needs adequately. A new urban reality is taking shape: cities with shrinking, vulnerable, and socially weakened populations (Copeland, 2020). Economic threats make recovery and development virtually impossible without external international support. The reduction in employment opportunities and the shrinking number of economically active citizens lead to decreased tax revenues, which in turn undermine the ability to maintain even basic functions of urban infrastructure. Attacks on the national energy system make the electricity supply unstable, especially during winter months when the demand on networks increases significantly. Limited resources for repair, reconstruction, and modernisation render many degradation processes irreversible.

Investors avoid Ukrainian cities due to high levels of risk, while existing industries have either been evacuated or are

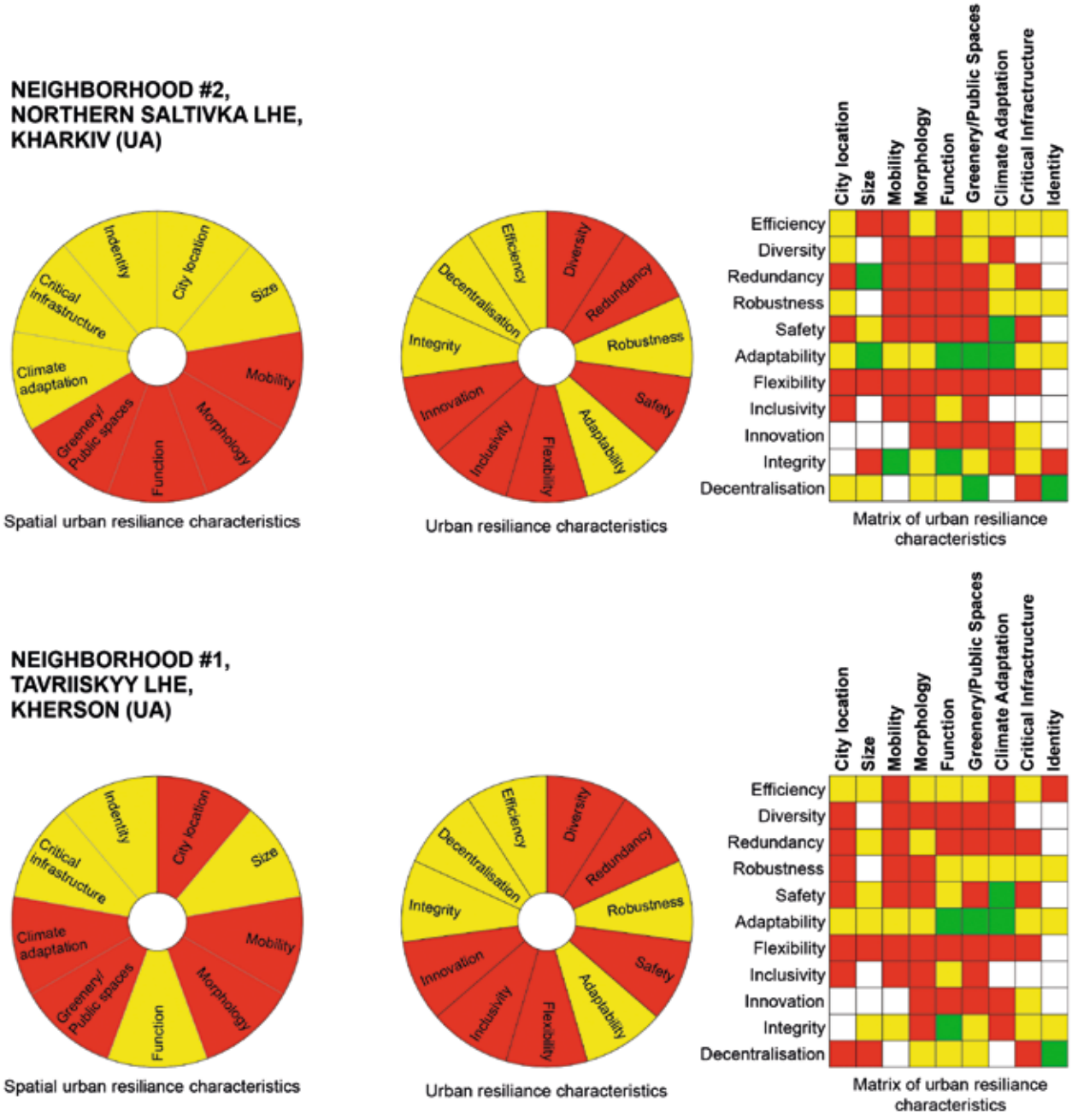

Fig. 6. *Sectoral diagram of spatial urban resilience. Sectoral diagram of resilience characteristics assessment. Matrix for assessing spatial urban resilience. Ukrainian neighbourhoods (Kharkiv, Kherson). Developed by Nadiia Antonenko*

experiencing stagnation. This slows not only economic growth but also the cities' capacity to respond to other threats, creating a cumulative effect that further undermines resilience (Voss, M., & Klohn, 2014). This creates urban instability, where large housing estates constantly respond to crises, making long-term planning and sustainable development seem nearly utopian.

Within this study, a comprehensive methodology was developed to analyse the resilience of the spatial characteristics of large-scale housing estates. This methodology is based on the interrelation of three key factors through a conventional sectoral planning framework, and resilience characteristics that determine the overall resilience of a neighbourhood as an integrated urban system. In the first stage, each characteristic was compared with ideal spatial resilience characteristics. Depending on the degree of alignment with the ideal model, each feature was assigned one of three scores: positive, moderate, or negative. The results of this comparative analysis were visualised using circular diagrams, which reflected both the overall resilience status of each specific neighbourhood and the resil-

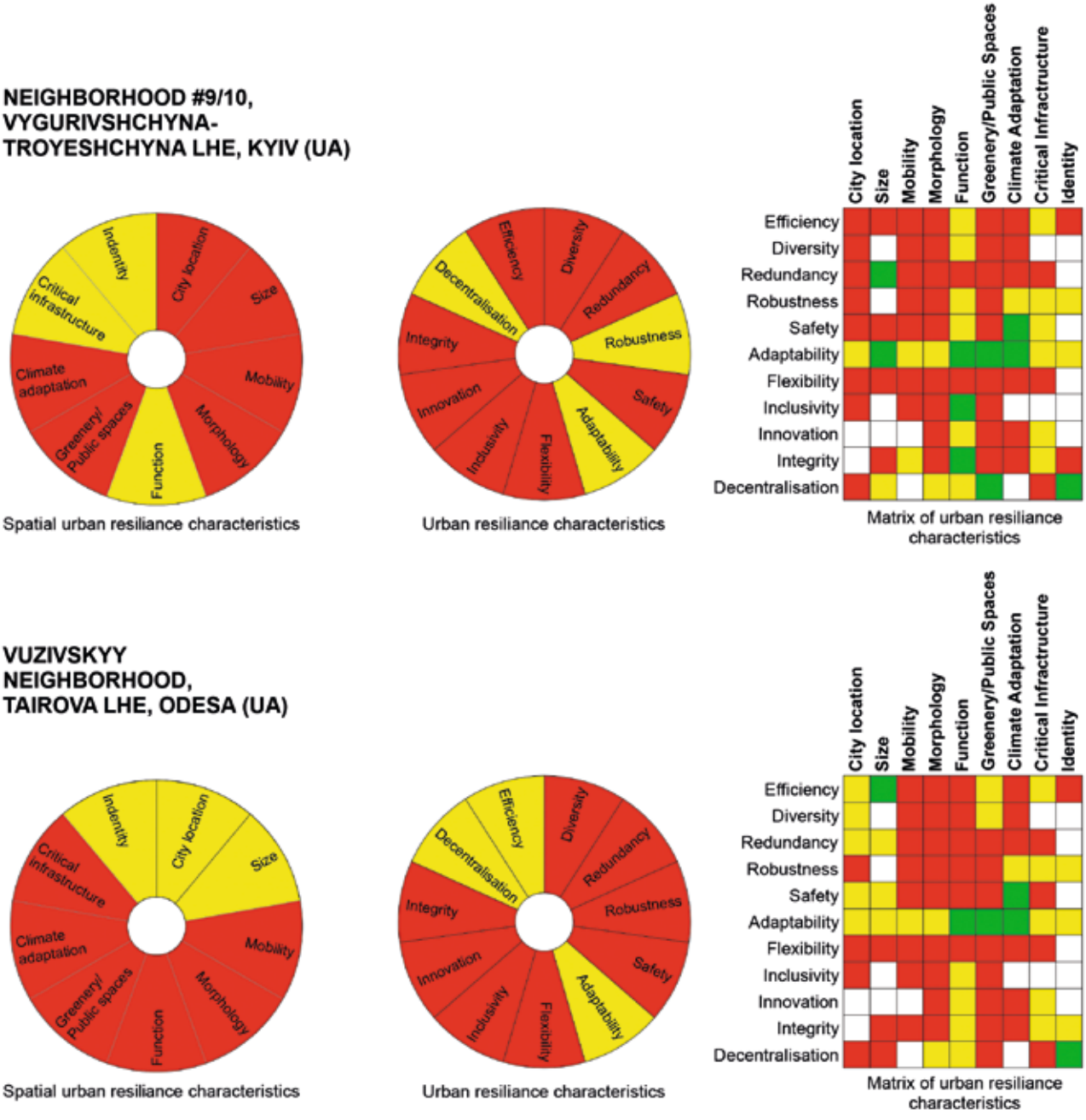

Fig. 7. *Sectoral diagram of spatial urban resilience. Sectoral diagram of resilience characteristics assessment. Matrix for assessing spatial urban resilience. Ukrainian neighbourhoods (Kyiv, Odesa). Developed by Nadiia Antonenko*

ience levels of individual spatial layers, such as green, reas, social infrastructure, public spaces, and others.

In the next stage, the analysis focused on how resilience characteristics—such as efficiency, diversity, innovativeness, inclusivity, and others—respond to various types of threats, including economic, social, environmental, and geopolitical challenges. A specialised multi-component questionnaire was developed to assess the impact of each type of threat on resilience attributes. Using data collected through this questionnaire, a detailed analysis was conducted for each spatial layer's resilience characteristics. Parameters such as size, spatial location within the urban structure, morphology, functional designation, and others were examined. These data were systematised and presented as matrices reflecting the interconnections between resilience characteristics and corresponding spatial resilience characteristics. These matrices allowed for a visual identification of vulnerable elements within the urban fabric of each neighbourhood, highlighting layers with high potential for resilience development, and uncovering the causes of spatial vulnerability, whether due to insufficient flexibility, limited inclusiveness, or a low capacity for adaptation to change. The analysis results were supplemented by two synthesised circular diagrams. The first illustrated the general intensity of resilience characteristics, classifying them as strong, moderate, or weak.

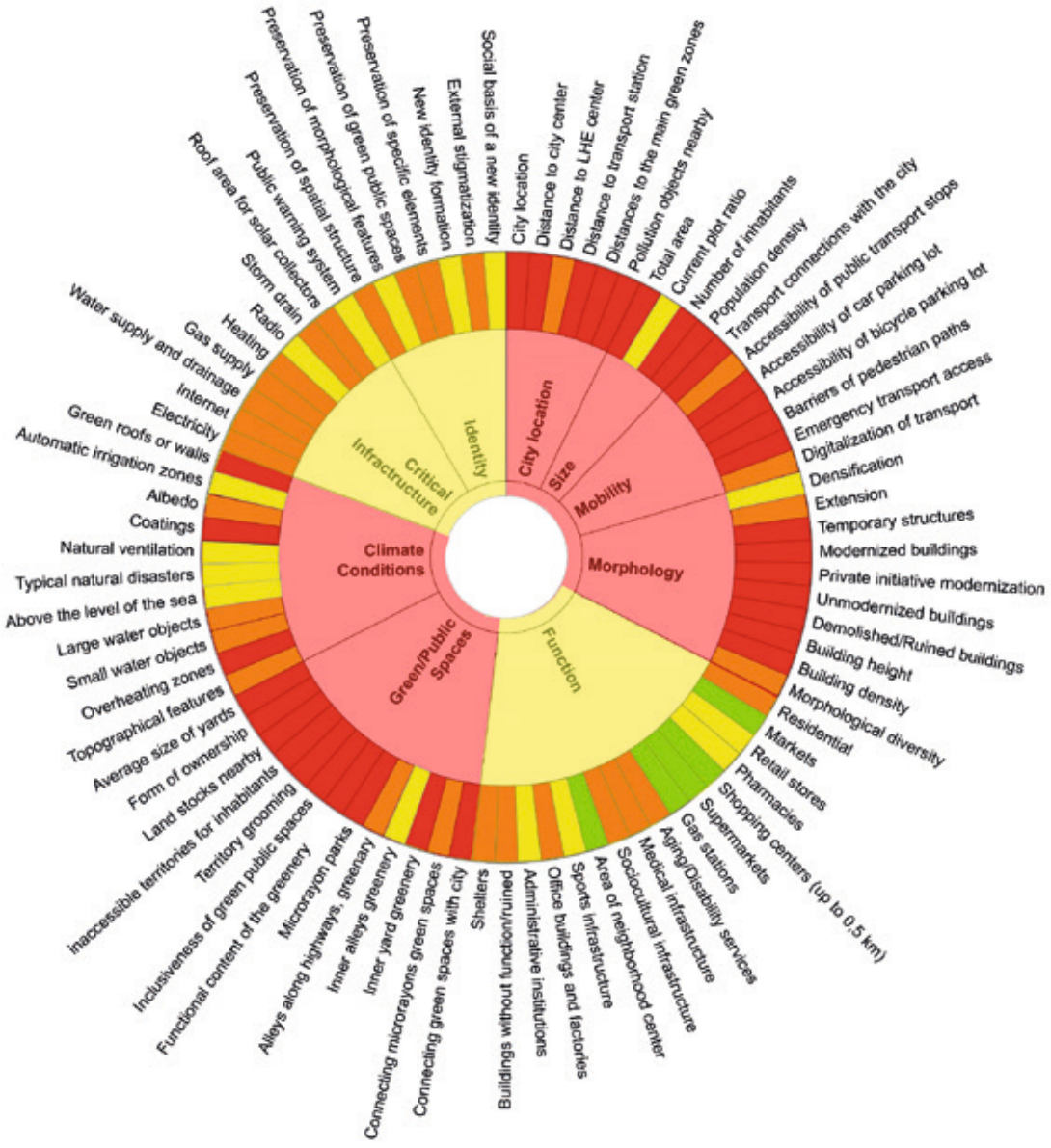

Fig. 8. *Spatial resilience of neighbourhood No. 9/10 in the Vygurivshchyna-Troieshchyna large-scale housing estate of Kyiv. Sectoral diagram of spatial resilience characteristics. Developed by Nadiia Antonenko*

The second displayed resilience levels across each spatial layer. This diagram served a corrective function about the overall neighbourhood resilience diagram, since spatial parameters, despite formal compliance with regulations, do not always ensure actual resilience, either quantitatively or qualitatively. To eliminate potential ambiguity and improve the accuracy of result interpretation, the methodology included the overlaying of both diagrams. This led to the emergence of additional intermediate colour values in the circular diagrams, allowing for a more detailed assessment of spatial resilience levels and identification of potential development directions or areas of highest risk. Thus, the combination of visualised diagrams with the results of matrix analysis forms a comprehensive analytical tool that supports comparative assessment of different territories, identification of their strengths and weaknesses, and the well-founded design of strategies to enhance urban resilience at the neighbourhood level (Fig. 6-10).

Spatial Layer "Size"

Neighbourhoods No. 9/10 (Vygurivshchyna-Troieshchyna large-scale housing estate, Kyiv) represent an enlarged-scale neighbourhood — 73.5 ha. On the one hand, such a large area implies the presence of spacious courtyards and inter-yard spaces and can be used for the construction of essential facilities, the

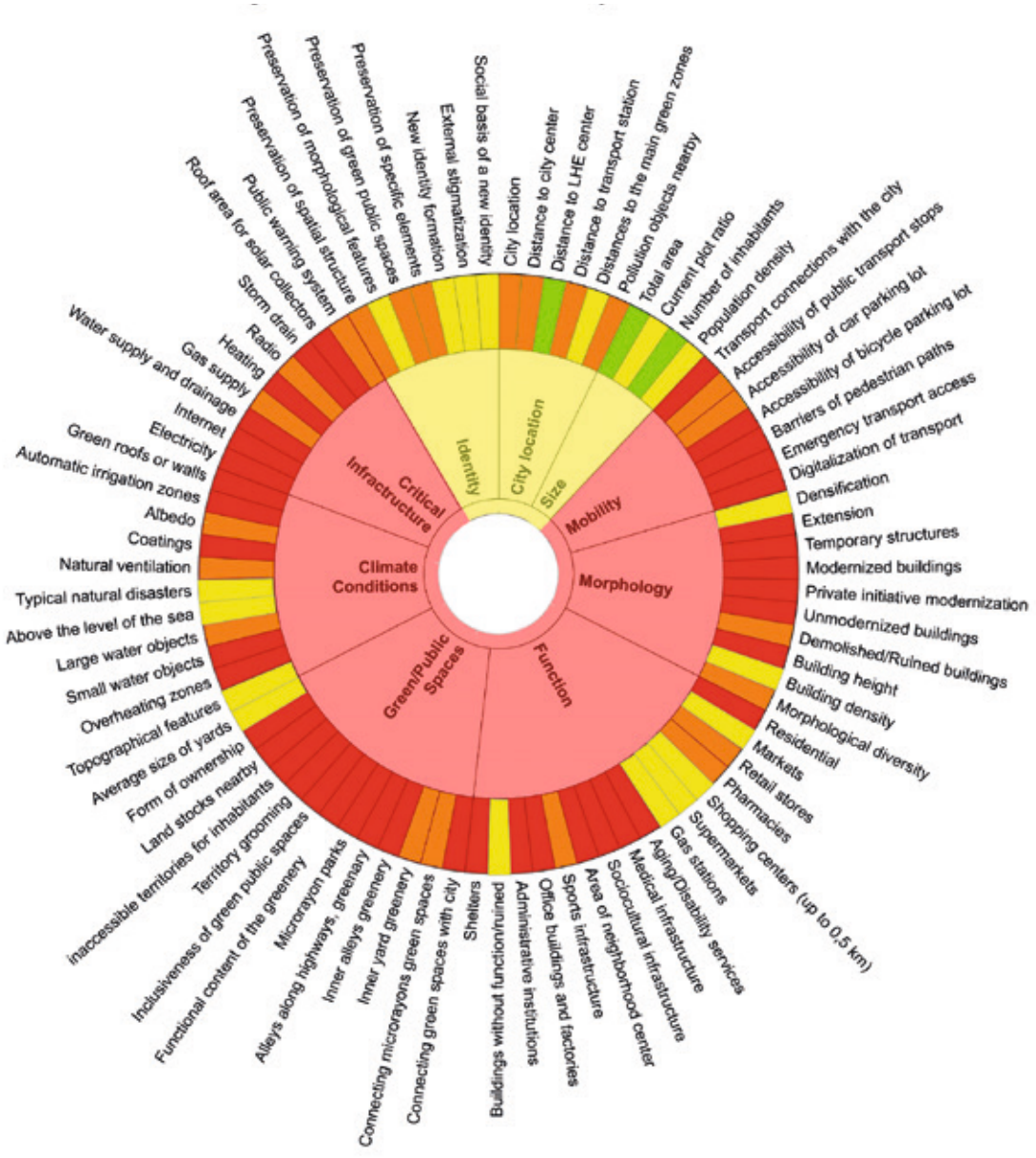

Fig. 9. *Spatial resilience of the Vuzivsky neighbourhood in the Tairova large-scale housing estate of Odesa. Sectoral diagram of spatial resilience characteristics. Developed by Nadiia Antonenko*

Implementation of natural drainage systems, the expansion of green zones, the development of decentralised energy networks, and the placement of temporary shelters. On the other hand, in wartime conditions, the neighbourhood's size and high population density (up to 34,200 people/km²) place enormous pressure on infrastructure during evacuation and pose significant management challenges in critical situations. Large distances between buildings can act as buffers, but they also complicate the rapid sheltering of residents due to the long distances to shelters, heating stations, humanitarian centres, and territorial defence hubs. Wide streets and courtyards may be used for the placement of military equipment, which further increases the risk of civilian casualties. In contrast, the Vuzivsky neighbourhood (Tairova large-scale housing estate, Odesa) represents a relatively compact territory of 38.6 ha, with a building coverage ratio of 0.23 and a population density of approximately 28,200 people/km². Its spatial organisation is more balanced, and the neighbourhood's size contributes to moderate spatial resilience. Dense development, proximity of residential buildings, and limited area support stronger awareness of community needs, faster self-organisation in response to external threats, and everyday social interactions that reinforce internal ties. The compactness of the neighbourhood also means that restoring damaged infrastructure requires less time and investment.

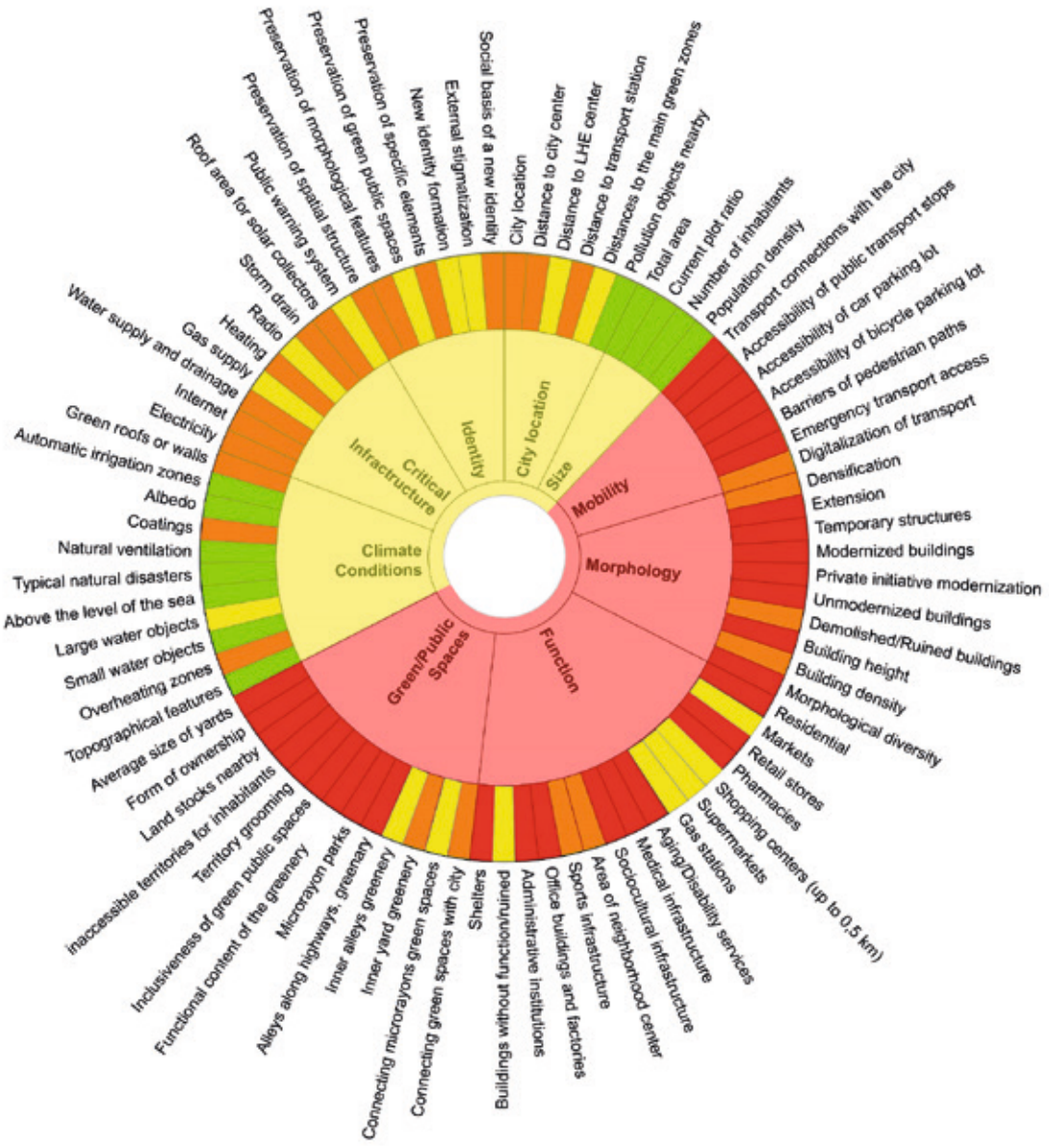

Fig. 10. *Spatial resilience of neighbourhood No. 2 in the Northern Saltivka large-scale housing estate of Kharkiv. Sectoral diagram of spatial resilience characteristics. Developed by Nadiia Antonenko*

For instance, water supply repairs, setup of autonomous heating systems, or restoration of power lines can be carried out more quickly due to the spatial proximity of infrastructure. Dense development also imposes certain limitations: the lack of physical space hinders the creation of new shelters or new green areas; access to open spaces is limited. From a safety perspective, the neighbourhood benefits from its compactness, location, and building density: it holds little strategic value for military operations. At the same time, the proximity of buildings increases the risk of destruction in the event of missile strikes.

Neighbourhood No. 1 (Tavriiskyi large-scale housing estate, Kherson) is another example of how small size (37.9 ha) and balanced population density (pre-war — up to 31,600 people/km²; during the war — less than 15,800 people/km²) contribute to spatial resilience. The compactness of the neighbourhood enables efficient resource allocation, quick response to challenges, and the launch of local recovery initiatives, as well as the organisation of evacuation efforts. Social connectedness in the Tavriiskyi large-scale housing estate is higher than in other neighbourhoods, which is related to its compact structure. People know their neighbours and are engaged in local initiatives, fostering the development of horizontal trust-based relationships. During the war, undeveloped spaces proved insufficient, limiting flexibility in placing temporary shelters or creating autonomous energy solutions in wartime conditions. High-rise buildings and narrow pas-

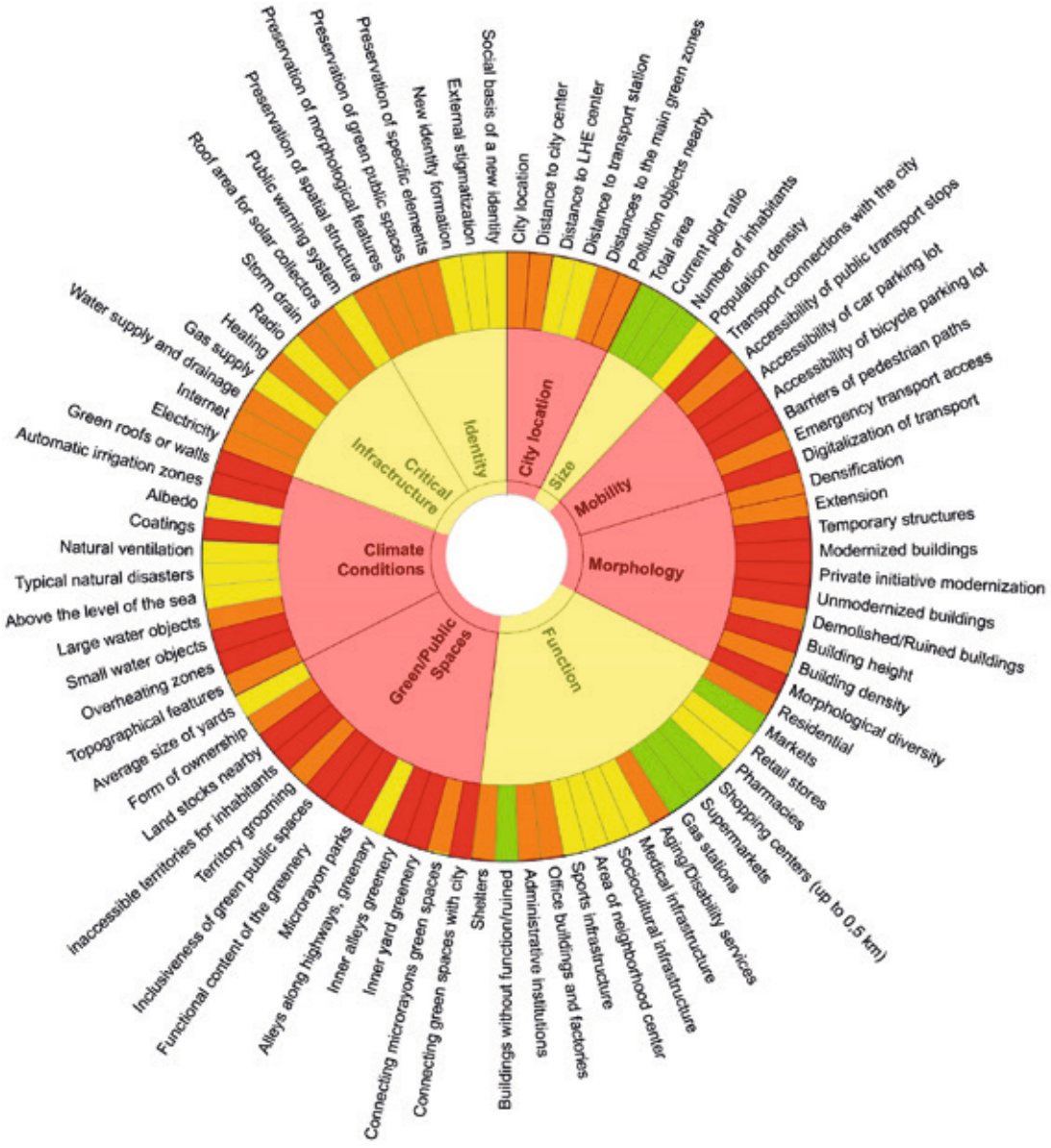

Fig. 11. *Spatial resilience of neighbourhood No. 1 in the Tavriiskyi large-scale housing estate of Kherson. Sectoral diagram of spatial resilience characteristics. Developed by Nadiia Antonenko*

sages between them increased the area's vulnerability to blast waves and made evacuation more difficult.

Neighbourhood No. 2 (Northern Saltivka large-scale housing estate, Kharkiv) with an area of 42.8 ha and moderate population density (pre-war — 27,900 people/km²; post-war — around 13,900 people/km²), the neighbourhood maintains a manageable spatial scale and offers opportunities for the placement of new civil protection facilities, greening initiatives, and functional redistribution. However, a significant portion of the area is currently used inefficiently: vacant zones are not integrated into the city's functional network. Social ties in the neighbourhood have weakened — the population has sharply declined due to widespread destruction, although signs of resilient local communities are beginning to emerge. Under conflict conditions, the presence of spacious courtyards has become a vulnerability. In the early months of the war, buildings functioned as defensive structures and thus became targets for shelling, resulting in damaged housing and increased fatality risks for residents. The current demographic situation, marked by significant population outflow, creates a foundation for replanning and the implementation of more radical solutions than would be feasible in less affected areas. This neighbourhood, like the heavily damaged neighbourhood No. 1 in the Tavriiskyi large-scale housing estate of Kherson, could serve as a testing ground for new post-war housing formats — including large-scale residential reconstruction, the introduction of new building typologies, nature-based infrastructure, and resilient public spaces.

The analysis of the "size" spatial layer in the Ukrainian neighbourhood has shown that this layer has a complex impact on their resilience. This impact is not linear. Both excessive scale and extreme compactness can become sources of vulnerability. Everything depends on a unique combination of factors — the quality of spatial organisation, the efficiency of open space use, the potential for spatial transformation, functional flexibility, the level of social connectedness, and the nature and intensity of external threats. Neighbourhoods with medium size, balanced population density, and access to adaptable spaces tend to be the most resilient. This is evident in neighbourhood No. 2 (Northern Saltivka large-scale housing estate, Kharkiv) and neighbourhood No. 1 (Tavriiskyi large-scale housing estate, Kherson), where ongoing threats have fostered strong community cohesion. In contrast, the large-scale neighbourhoods No. 9/10 in the Vygurivshchyna-Troieshchyna large-scale housing estate require in-depth strategic planning, spatial revitalisation, community activation, and significant financial investment to unlock their latent potential.

Spatial Layer "City Location"

Neighbourhoods No. 9/10 (Vygurivshchyna-Troieshchyna large-scale housing estate, Kyiv) are located in the central part of a large housing development in the northeastern section of the city. Although officially within city limits, these neighbourhoods are effectively situated on the urban periphery. Since its construction, the Vygurivshchyna-Troieshchyna housing estate has remained isolated from the rest of the city, both infrastructurally and socially. This is due to the absence of a metro line (originally planned during the design phase), the overload of roadways leading to the right bank of the city, and weak spatial and functional integration with other districts. The neighbourhood's distance from the city centre — approximately 9.6 km — is critical. In the absence of underground transit, surface transportation is prone to disruptions, making access to the city centre unreliable and unsafe. Connectivity to intercity and international transport hubs is also insufficient: the nearest transport nodes are located 6 to 16 km away. Private vehicles remain the only reliable means of leaving the area, limiting equitable access to safety resources. In wartime conditions, evacuation routes are restricted to bridges that are vulnerable to overload or destruction, with few alternative routes available. As a result, fast and safe evacuation during emergencies becomes impossible. The distance to local sub-centres, such as the Troieshchyna market (1.9 km), is relatively acceptable, though improvements in pedestrian and street infrastructure are required. One of the few positive aspects of the neighbourhood's location is the availability of green spaces within walking distance. However, their integration into the city's ecological network remains ineffective. The environmental situation is further complicated by the proximity of potentially hazardous facilities, particularly CHP-6 (3.2 km away) and the National Bank's printing complex (1.2 km away). The overall resilience of the "city location" spatial layer of neighbourhoods No. 9/10 is extremely low.

The Vuzivsky neighbourhood (a large-scale housing estate in the Tairova district of Odesa) is characterised by pronounced peripherality. Its spatial location within the city structure can be described as having moderate resilience. Despite this, it is much better integrated into the overall urban fabric compared to neighbourhoods No. 9/10 in the Troieshchyna-Vyhurivshchyna area of Kyiv. Travel to the city centre (8.6 km) often takes more than an hour due to traffic congestion, which reduces the efficiency of both daily and emergency logistics. The nearest intercity transport hubs are located outside the 3 km radius zone: the railway station is 6.3 km away, the central bus station is 7.3 km away, and the airport, out of service since 2022, is 5.3 km away. This

also significantly limits the possibilities for independent evacuation from the city. In emergencies, this dependence becomes especially critical for low-income residents who do not own personal vehicles or have the means for independent evacuation. The neighbourhood maintains functional self-sufficiency in terms of access to essential goods and services. In addition to small commercial outlets, there is the "Vuzivskyi" shopping centre and the "Kyivskyi" market, located 1.1 km from the residential area. Most residents regularly commute to other parts of the city for work. This adds strain to the transportation system and makes the area dependent on external economic centres. Another vulnerability of the Vuzivsky neighbourhood's location lies in its spatial isolation—connections to natural landscapes and green corridors were not implemented. The neighbourhood is surrounded by low-rise cottage-style housing. The nearest city park is in the adjacent Cheremushki area (1.9 km), while other green zones are located 2 to 3.7 km away. At a distance of 1.9–2.5 km, there are pharmaceutical enterprises as well as gasification and machine engineering facilities, which have a moderately negative impact on the neighbourhood's ecological environment.

Neighbourhood No. 1 (Tavriiskyi large-scale housing estate, Kherson) demonstrates a higher, though still insufficient, level of resilience. The location of the neighbourhood in the northwestern part of the city ensures a moderate distance from the centre (3.2 km). Proximity to key transport hubs, such as the railway station (1.4 km) and Bus Station No. 1 (1.5 km), provides a foundation for rapid evacuation and the delivery of humanitarian aid. However, despite the favourable location of the neighbourhood, the number of evacuation routes is limited (three exits from the city), and personal transport remains the only reliable way to leave the area. Constant shelling significantly reduces the actual effectiveness of these routes, making movement extremely difficult, especially for socially vulnerable population groups. From the perspective of integration into the city's ecological system, the neighbourhood has potential, but with limitations — its green zones are poorly connected to the overall biosphere of the city and district, indicating low self-purification capacity and a disrupted climate balance. Within a 3 km radius of the neighbourhood, there are industrial facilities (including machine-building, electromechanical, and oil-processing plants, as well as a thermal power station), but these enterprises are currently non-operational, and the ecological burden is minimal.

Neighbourhood No. 2 (Northern Saltivka large-scale housing estate, Kharkiv) has a moderately low level of resilience. It demonstrates a spatial compromise between self-sufficiency and peripherality. Located in the northeastern part of the city, about 9 km from the centre, it lies on the edge of urban development. The pedestrian accessibility of the "Saltivska" metro station (1.5 km) partially compensates for the transport isolation, considering the significant distance from the railway station (11.5 km) and the airport (13.7 km). The primary method of evacuation in crisis conditions is the use of private vehicles. Evacuation is complicated during crises. There is no reserve infrastructure, and evacuation routes can be easily blocked. The distance from the centre is partially offset by proximity to the city sub-centre near the "Saltivska" metro station, which concentrates commercial and recreational activities. Although green corridors have not yet been integrated into a full-fledged infrastructure, the area's green structure has all the prerequisites for effective inclusion into the citywide ecological network. There are no industrial enterprises within or near the neighbourhood, which creates the basis for a favourable environmental situation.

Analysis of the spatial layer "city location" shows that, despite the current difficult military situation, neighbourhood No. 1 in the Tavriiskyi large-scale housing estate remains the most resilient in terms of spatial characteristics. It is relatively close to the city centre, connected to key transport hubs, includes a potentially strong recreational and commercial core, and is characterised by favourable environmental conditions with minimal technological risks. Neighbourhood No. 2 in Northern Saltivka and the Vuzivsky neighbourhood demonstrate a lower level of resilience due to evacuation difficulties. Neighbourhoods No. 9/10 in Kyiv are in the most critical situation due to the absence of a metro, significant distance from the centre, weak integration into the city's transport network, and the concentration of potentially hazardous sites nearby.

Spatial Layer "Morphology"

The morphology of neighbourhood No. 9/10 in the Vygurivshchyna-Troieshchyna large-scale housing estate is characterised by high building density (1.46), which increases the area's vulnerability to contemporary threats, including war, natural disasters, and social issues. The neighbourhood is dominated by typical high-rise residential buildings (up to 23 floors), which is a key factor amplifying its vulnerability. These structures pose additional risks—high-rise buildings are especially susceptible to missile strikes, and their collapse can result in mass casualties. Even localised damage to critical infrastructure, such as water supply, electricity, and heating systems, can cause immediate suffering for thousands of residents. Problems related to building energy efficiency, outdated

utility networks, and a lack of funding for major repairs only worsen the situation. Evacuation from high-rise buildings is also significantly more difficult. The neighbourhood is also vulnerable to climate change. High-rise buildings are prone to overheating, which leads to intensive use of air conditioning, increasing energy consumption and negatively impacting the climate through carbon emissions. High population density further complicates the integration of diverse social groups and hinders the development of resilient social networks and mutual support systems. Public buildings—such as schools, kindergartens, and shops—are also based on standardised design solutions. These morphological characteristics make it difficult to implement new architectural ideas and limit the flexibility of transforming the existing morphology of the neighbourhood. The situation with retail outlets—often represented by temporary structures—also has a negative impact. These can become sources of social tension and criminalisation. Temporary constructions are often built in violation of safety regulations and can lead to local fires and other hazards. At present, the Vygurivshchyna-Troieshchyna housing estate is in a critical risk zone, but due to its distance from the front line, it has not yet suffered significant destruction.

The Vuzivsky neighbourhood (Tairova large-scale housing estate, Odesa) features more varied morphology. After 1991, active construction continued in the area: in addition to standard Soviet-era buildings, individually designed structures appeared — new residential complexes, commercial buildings, and developments with underground parking. The neighbourhood's morphology, with small semi-enclosed courtyard spaces, creates better conditions for the formation of resilient local communities than in Kyiv. However, the residential buildings, predominantly constructed with prefabricated panels, have a number of morphological limitations. The neighbourhood is vulnerable to social and economic crises — built-in spaces and ground floors are inconvenient for introducing new functions, and despite the proximity of large shopping centres and a market, these spaces are rarely used for commercial purposes. Efforts to modernise and improve the energy efficiency of houses are localised and uncoordinated. Housing management bodies and homeowners' associa-

Fig. 12. Morphological changes in the Vuzivsky neighbourhood after 1991. DAAD, 2023-2024

tions, where they exist, often face limited resources and are unable to implement a comprehensive approach to energy efficiency upgrades, major structural repairs, or modernisation of utility systems. Entrances to residential and public buildings are often not equipped with ramps, or the ramps are not ergonomic. In wartime conditions, under the threat of missile strikes, the vulnerability of high-rise panel buildings becomes critical: the weak structural stability of the panels can lead to partial or complete collapse (Wikipedia, 2025). The issue of waterlogged basements makes it impossible to convert them into shelters. Beyond military threats, the height of buildings also increases risks during extreme heat. Elevated facade surface temperatures and the constant need for air conditioning lead to higher energy consumption and increased carbon emissions.

An additional threat is posed by the extensive presence of temporary structures — garages and kiosks — which are widespread in the neighbourhood and form entire spatial systems. They obstruct evacuation and emergency operations and contribute to the spread of fires. These structures have also become centres of local criminal activity, undermining social trust (Fig. 12). The morphology of the neighbourhood demonstrates low resilience. However, the potential transformation of enclaves occupied by temporary structures preserves opportunities for morphotypical changes.

In neighbourhood No. 1 (Tavriiskyi large-scale housing estate, Kherson), the potential for morphological transformation is limited by the characteristics of prefabricated high-rise housing (standard 9- and 16-story buildings). The neighbourhood has retained its original layout and functional structure. Mid-rise blocks with semi-enclosed courtyards have provided a foundation for the development of stronger social ties. Since 1991, morphological changes have been minimal, consisting mainly of facade insulation and balcony glazing. High-rise buildings are at increased risk of destruction. According to preliminary estimates as of 2024, approximately 60% of buildings have been damaged by shelling. Although part of the housing stock remains undamaged and is technically subject to restoration, the feasibility of such restoration is questionable, as it is

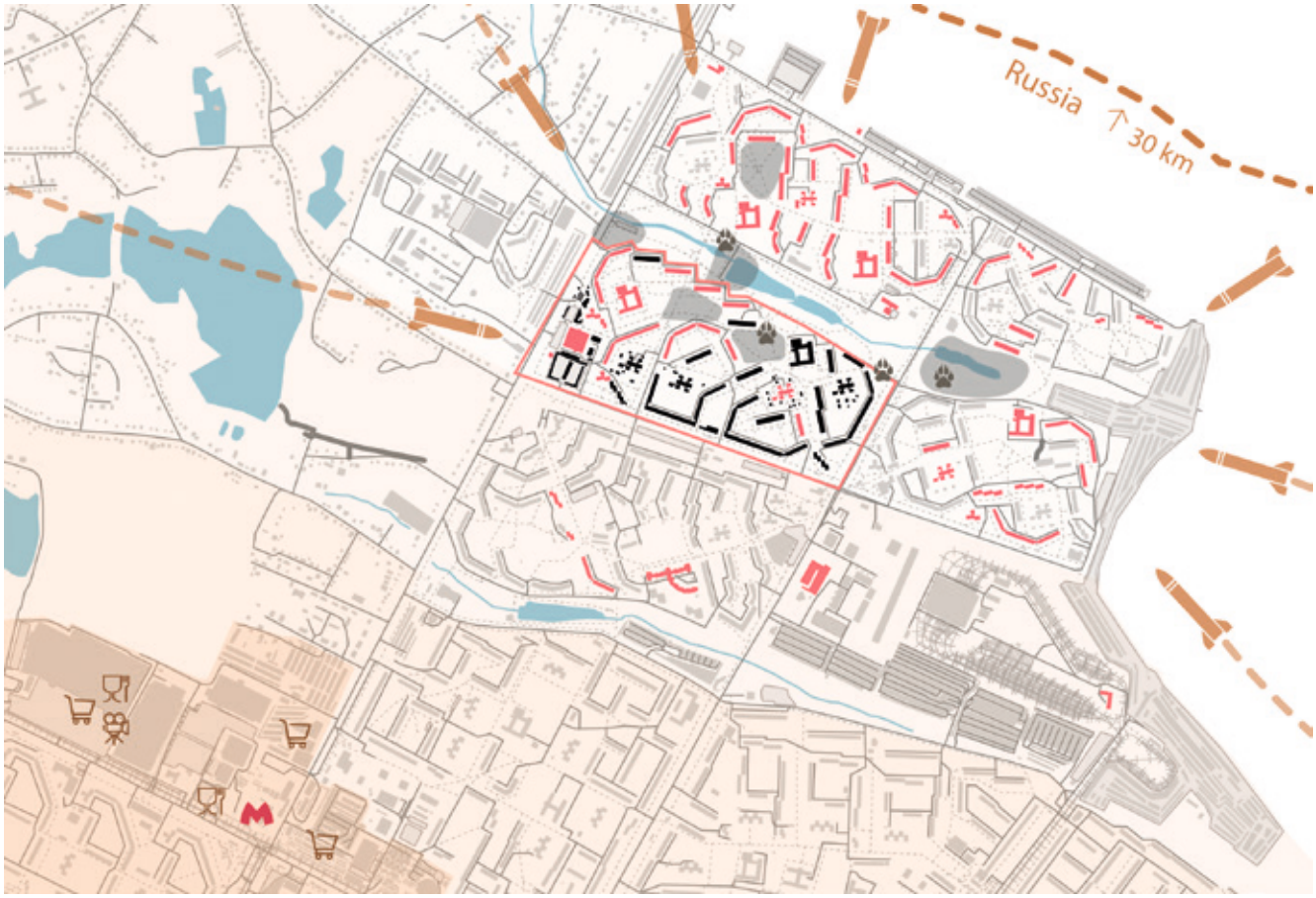

Fig. 13. Current threats in the Northern Saltivka large-scale housing estate in Kharkiv. Buildings marked in red were damaged as of the end of 2023. DAAD, 2023-2024

unclear how many residents will return to the neighbourhood for permanent residence after the war. The demographic crisis in this neighbourhood is more severe than in the other areas analysed: the population is declining, the housing stock is deteriorating, and the proportion of elderly residents is significantly increasing. Apartment-by-apartment privatisation of the housing stock remains a major barrier to large-scale transformation. After the war, ensuring decent living conditions will require a thorough analysis of the remaining morphology and the development of new solutions that address both the real needs of residents and modern housing standards.

Neighbourhood No. 2 (Northern Saltivka large-scale housing estate, Kharkiv) is one of the most heavily damaged residential areas in the city. The predominant building type is similar to that of neighbourhood No. 1 in Kherson—nine- and sixteen-story panel buildings. The area demonstrates a "patchwork" approach to facade repairs and occasional extensions to building entrances on the ground floors, which have been repurposed as non-residential spaces.

Like other neighbourhoods, it lacks inclusivity: the needs of people with disabilities are not taken into account, which becomes critical during evacuations. Morphologically, the area suffered extensive destruction during the war. Damage from missiles and shells has led to partial building collapses (Fig. 13). Before the war, the neighbourhood had a moderate level of social activity. This was largely due to a high percentage of young families with children who spent considerable time outdoors, interacting on playgrounds and in educational and recreational facilities. The destruction and population outflow triggered a demographic crisis, which has not been offset by external migration. At the same time, stronger neighbourhood ties have developed among those who remained. The proportion of elderly residents is increasing. Due to the low building density (0.92) and war-related destruction, the neighbourhood's morphology has potential for transformation. However, the resilience of the morphology of neighbourhood No. 2 remains low. It is insufficiently adaptive and highly vulnerable in terms of safety, inclusivity, and flexibility.

Analysis shows that the most morphologically vulnerable areas are neighbourhood No. 2 in Northern Saltivka and neighbourhood No. 1 in the Tavriiskyi large-scale housing estate, due to their proximity to the front line—panel high-rises are extremely vulnerable to shelling. This morphological type is also susceptible to climate and economic challenges. Apartment-by-apartment privatisation critically hinders the potential for rethinking neighbourhood morphology in the postwar period. The physical destruction of high-rise residential buildings may become a catalyst for development, but only if there are significant postwar investments, well-designed and integrated urban planning solutions, and a fundamental revision of national housing policy.

Spatial Layer "Mobility"

Neighbourhoods No. 9/10 (Vygurivshchyna-Troieshchyna large-scale housing estate, Kyiv) represent one of the most complex cases among the neighbourhoods studied. Nearly all types of transport are present here: trolleybuses, buses, informal private minibuses, high-speed trams, and suburban trains; access to the metro is limited, located at a distance of 5.9–6.2 km. Despite this apparent diversity, mobility within the neighbourhood is effectively constrained by the dominance of private vehicles and minibuses. The high density of public transport stops (approximately every 300 meters) provides a basic level of accessibility. However, the distance from stops to protective shelters exceeds the military-recommended maximum of 50 meters (Fig. 16). Underground shelters along routes to stops and bus stops equipped as shelters are rare or completely absent. Automobile infrastructure is moderately developed: the area includes private garages, free and paid parking, but lacks car-sharing and car rental services. The total area allocated for parking is 2.2 hectares—3.6% of the total neighbourhood area, which is insufficient given the current population density. The pedestrian environment contains numerous barriers: lack of ramps, poor pavement conditions, widespread fencing, and other physical obstacles. Evacuation and emergency logistics capabilities in the neighbourhood are limited: spontaneous and unregulated parking obstructs emergency vehicles, road surfaces are partially in poor condition, and the distance to the nearest emergency services exceeds 2.5 km. Lack of coordination between local and citywide transport systems makes both intra-district and inter-district travel inefficient and costly. The transport infrastructure has almost no redundancy: failures in one mode are not compensated by alternative routes, creating critical vulnerabilities in emergencies (Fig.14). Bicycles can complement the system (there are bike lanes connecting the Vygurivshchyna-Troieshchyna estate to the right bank), but they are not a universal solution. However, under wartime conditions, the neighbourhood's mobility is highly vulnerable and requires systemic revision.

The Vuzivsky neighbourhood (Tairova large-scale housing estate, Odesa) exemplifies an area with a low level of transport resilience. The transportation system is unstable, in-

flexible, non-inclusive, and incapable of rapid adaptation. In the context of increasing external threats—from climate-related to military—this poses a direct risk to the safety and well-being of residents. The main modes of transport are informal minibuses (marshrutkas), trams, trolleybuses, and buses. The city lacks a metro system. Routes are poorly optimised, resources are used inefficiently, and traffic density increases sharply during peak hours, leading to congestion at major entry and exit points to the city centre. A high dependence on private vehicles exacerbates the problem, creating additional risks of system overload during critical situations.

Modifying routes, establishing backup lines, expanding the vehicle fleet, or introducing emergency traffic regimes is unfeasible due to the lack of logistical planning, technical capacity, and coordination. Under adverse conditions, the neighbourhood may become completely isolated. Public transport stops often lack not only concrete shelters for protection against missile strikes but also basic canopies to shield passengers from rain and sun. Vuzivsky is a prime example of a pedestrian environment full of barriers. Narrow sidewalks, worn-out surfaces, fences, the absence of ramps and accessible entrances, and a large number of enclosures create serious challenges for people with limited mobility (Fig. 15). Most pedestrian routes run along major external roads and do not adequately penetrate the residential fabric of the neighbourhood.

The resilience of neighbourhood No. 1 (Tavriiskyi large-scale housing estate, Kherson) is shaped by a wide range of threats. The main modes of transport are trolleybuses and private minibuses (marshrutkas). All routes run along major streets, while the inner parts of the neighbourhood remain poorly served. Public transport stops are located every 300 meters, and some include shelter infrastructure. Pedestrian movement involves even greater risks due to the lack of an adequate shelter system and the low density of urban development. Most residents prefer to use public transport to enter or leave the neighbourhood to minimise the time spent in open areas. Moreover, the pedestrian environment is not inclusive: there are no ramps, walkways are narrow, surfaces are damaged, and entrances are difficult to access. Some routes and buildings have been damaged by military action,

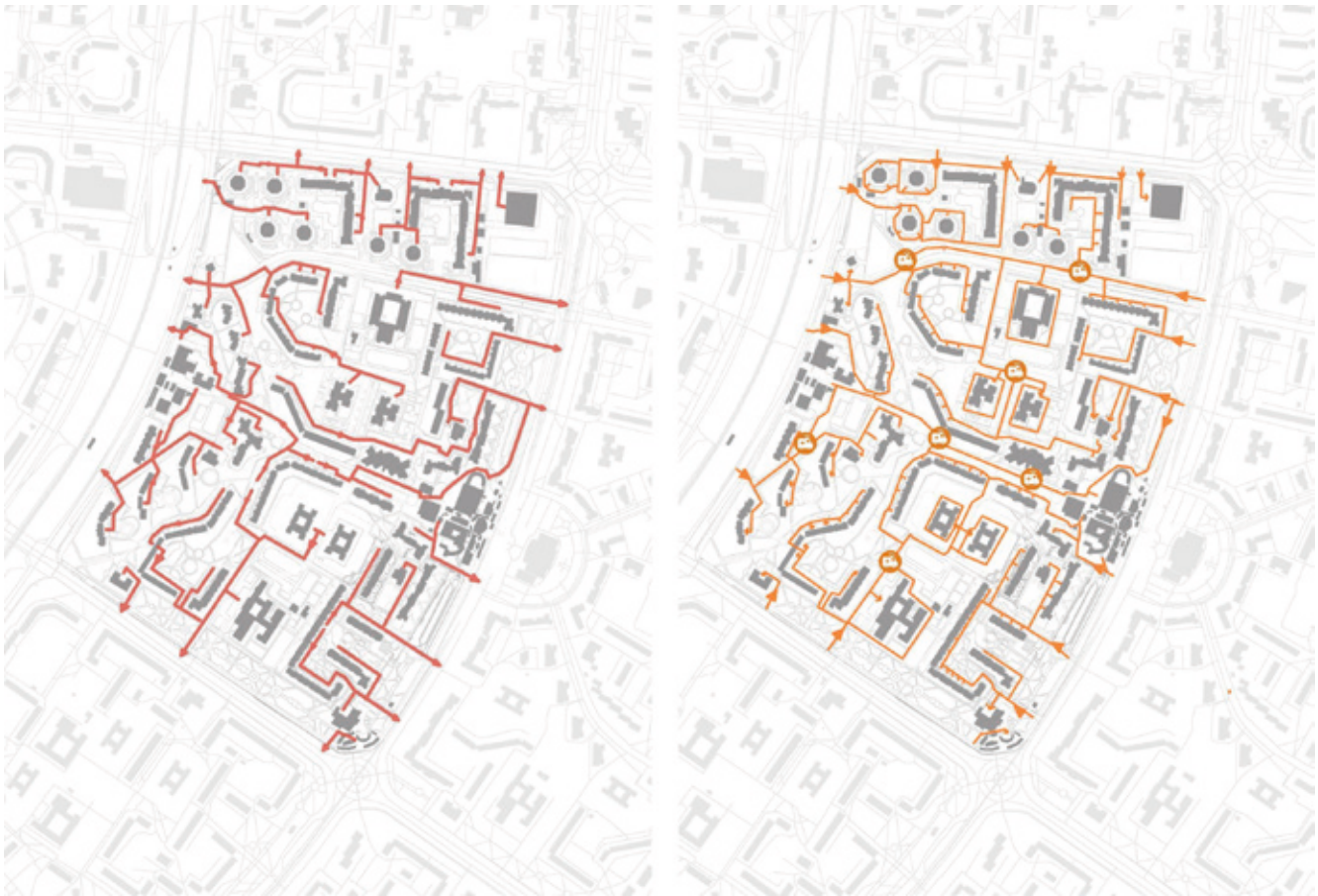

Fig. 14. Evacuation routes for residents of neighbourhoods No. 9/10 (Kyiv) and access routes for emergency vehicles. DAAD, 2023-2024

further complicating mobility. Despite the variety of transport options, their use remains inefficient.

Public transport suffers from overlapping routes operated by different providers and a lack of centralised control. This results in poor resource allocation and an inability to meet actual demand. As in other neighbourhoods, private vehicles remain the most effective means of transportation. They allow for rapid response to changing conditions and, in some cases, can be used for emergency evacuation. One of the key advantages of this neighbourhood is its proximity to emergency services (less than 1 km). The presence of a basic street network, the reliance on private vehicles, and experience gained from wartime adaptation provide a foundation for developing flexible and resilient transport solutions in the post-war period—solutions that can effectively respond to changing conditions and minimise risks during emergencies.

During the war, neighbourhood No. 2 (Northern Saltivka large-scale housing estate, Kharkiv) remains a high-risk area due to its proximity to the Russian-Ukrainian border (approximately 30 km). Key vulnerabilities include low safety levels, the absence of an inclusive environment, and weak connectivity with the rest of the city. Basic connections to other city districts are provided by trolleybuses, buses, and marshrutkas. A metro station is located 1.3 km away, which complicates its use by residents during emergencies. Rapid evacuation of the population is not feasible. As in other neighbourhoods, private transport remains the most effective means of mobility for both everyday use and emergency response. Public transport stops are spaced every 300–500 meters, and concrete shelter stops have been installed. However, access to emergency services is also limited. The level of inclusivity remains low: urban and transport infrastructure is not adapted to the needs of elderly people, persons with disabilities, and other vulnerable groups. Pedestrian routes are partially destroyed, while barriers and debris create serious obstacles to movement, especially for people with limited mobility, contributing to their isolation. The introduction of free public transport during wartime was a step toward supporting those in need, but it did not resolve the fundamental issues of accessibility and inclusivity. Metro expansion, moderni-

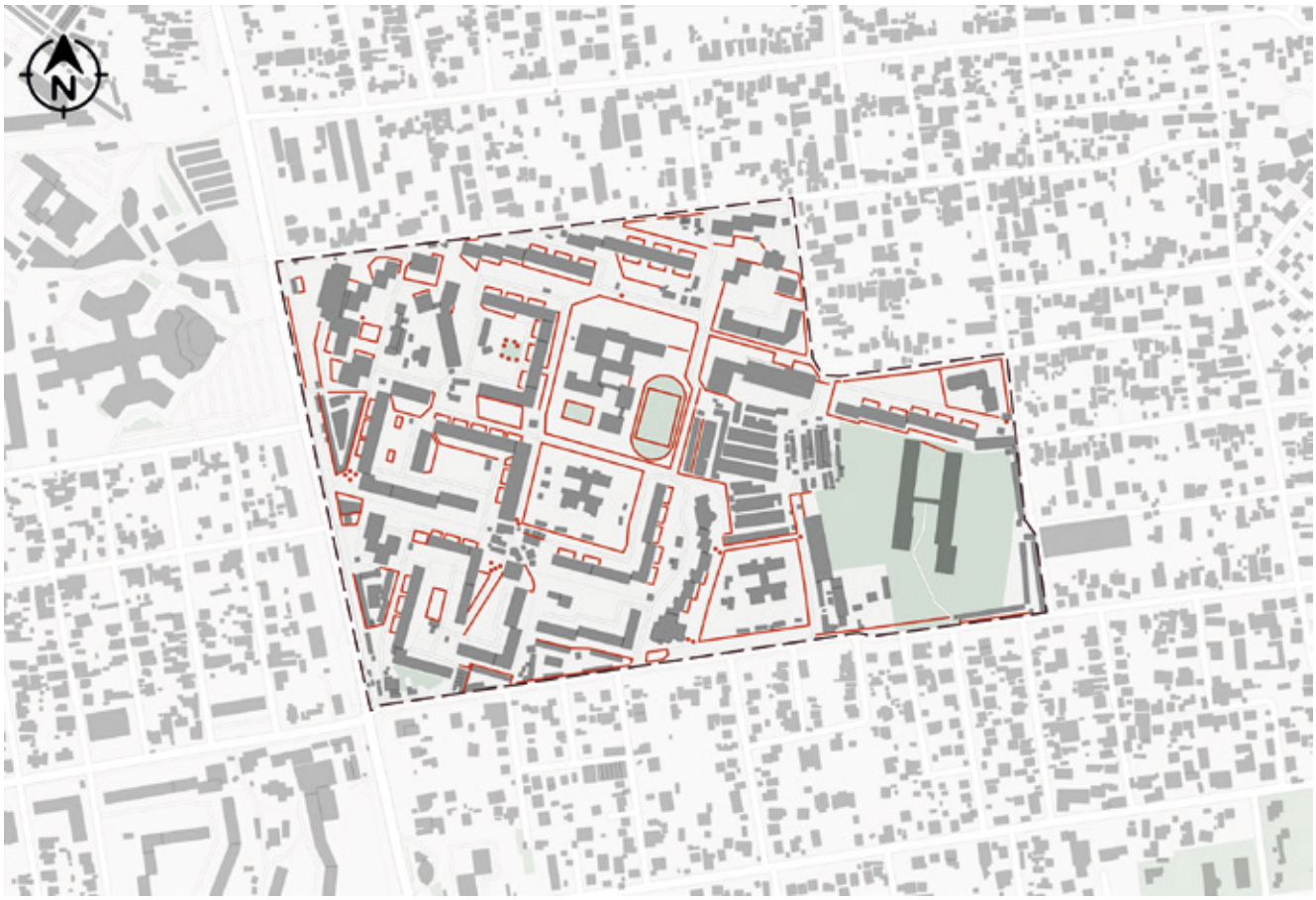

Fig. 15. Physical barriers in the Vuzivsky neighbourhood. DAAD, 2023-2024

sation of public transport, and the development of urban mobility strategies could become the foundation for enhancing resilience in the future.

None of the analysed neighbourhoods demonstrates a sufficient level of transport resilience. The most vulnerable in this context are the Vuzivsky neighbourhood in Odesa and neighbourhoods No. 9/10 in Kyiv. The most promising in terms of future transformation is neighbourhood No. 1 in Kherson, as it has greater potential for rethinking urban mobility at the citywide level.

Spatial Layer "Function"

Neighbourhoods No. 9/10 (Vygurivshchyna-Troieshchyna large-scale housing estate, Kyiv) represent an example of a functionally saturated but socially vulnerable urban area. The large central zone of the neighbourhood (6 hectares, 8.1% of the total area), high density of functions, developed network of rental spaces, and concentration of key facilities indicate the capacity of local businesses to respond, adapt, and transform following current needs. A dense network of commercial enterprises and service facilities has been formed here, including both large-scale entities — shopping and entertainment centres, supermarkets, markets — and smaller ones such as pharmacies, stores, beauty salons, notary offices, and others. The medical infrastructure includes both public and private institutions — laboratories, consultation centres, and clinics. The neighbourhood also contains elements of socio-cultural infrastructure, including educational institutions (kindergartens and schools), community centres, and religious facilities (Fig. 16). However, these are insufficient. There is virtually no socio-cultural support for elderly residents, former military personnel, people with disabilities, and low-income groups, all of whom make up a significant portion of the neighbourhood's population. High prices for goods and services, limited spatial accessibility, and the lack of affordable cultural and recreational spaces hinder integration and reinforce a sense of alienation among vulnerable population groups. In the event of an acute crisis, the number of markets, pharmacies, and medical facilities can provide short-term food and medical autonomy. At the same time, the civil safety infrastructure is in an unsatisfactory condition — the shelter system is not designed for the current population of the neighbourhood, with only 11 shelters and 5 resilience hubs available. Moreover, there is a lack of modern and flexible formats of public space, such as mobile medical stations, support centres, coworking spaces, etc., which hinders the rapid mobilisation of resources in emergencies. Meanwhile, the spatial structure of the neighbourhood, with large open areas between buildings, allows for the placement of additional basic infrastructure, civil protection facilities, and services for vulnerable groups. There is also development potential on the ground floors of buildings, which could be partially transformed from residential to commercial or civic use. The innovation potential of the neighbourhood is extremely low. The rapid creation of alternative employment opportunities is unlikely due to the absence of business incubators and innovation ecosystems in the housing estate, despite earlier attempts by city authorities to establish a technology park.

The functional resilience of the Vuzivsky neighbourhood (Tairova large-scale housing estate, Odesa) is assessed as low and more vulnerable compared to neighbourhoods No. 9/10 in Kyiv. The neighbourhood centre is underdeveloped, and most essential facilities are located outside its boundaries. Vulnerable population groups, which make up a significant portion of the neighbourhood's social structure, face the greatest risks. Retail outlets, pharmacies, cafes, and service facilities meet only basic daily needs, while key commercial, sociocultural, and medical institutions are situated outside the neighbourhood. The educational network is also poorly developed: the area includes only one school and two kindergartens. Medical services are limited and largely commercialised, which restricts access for socially vulnerable groups. The insufficient number of administrative and sociocultural facilities prevents the formation of a resilient internal infrastructure. The central part of the neighbourhood occupies only 0.3 hectares (0.7% of the total area), emphasising its dependence on external subcenters located beyond the neighbourhood, which undermines both its adaptability and autonomy. Since the beginning of the full-scale war, business activity in the neighbourhood has significantly declined (Fig. 17). There is also a lack of reserves of essential goods and services, which increases the area's vulnerability during crisis periods. The civil defence infrastructure is critically insufficient: the available number of shelters does not ensure the safety of all residents in the event of mass shelling.

Neighbourhood No. 1 (Tavriiskyi large-scale housing estate, Kherson) was originally planned as part of a large residential district, the implementation of which was not completed by 1991. A significant portion of the planned development was never realised: the city park remained an empty lot, and most of the planned household and socio-cultural infrastructure was not built. Even before the war, the neighbourhood faced a persistent shortage of service functions: retail, socio-cultural, administrative, educational, and medical infrastructure were much less developed here than in other parts of the city. The central part of the neighbour-

hood occupies only 1.1 hectares (2.9% of the total area), which is insufficient for it to function as a full-fledged local centre. Its limited functionality is partially offset by the presence of a market and shopping centre in a nearby neighbourhood, as well as two additional markets within a two-kilometre radius. However, some of these facilities were heavily damaged by massive missile strikes, significantly weakening the area's functional resilience under wartime conditions. One of the critical factors during the war is the insufficient number of facilities supporting evacuation: the limited availability of gas stations and maintenance services makes even individual evacuation from the area difficult. These limitations highlight the overall low level of functional flexibility and adaptability. Despite the presence of some spatial and infrastructural opportunities, their practical implementation is extremely constrained. The rapid deployment of new social institutions or the creation of alternative employment is currently nearly impossible. Some commercial and infrastructural facilities retain the ability to operate autonomously in the short term, particularly with the support of volunteer efforts. However, as these temporary resources become exhausted, the local system quickly becomes overloaded and loses resilience. Among the few positive aspects is the presence of clinics and pharmacies within walking distance, which enables the provision of basic medical care and the formation of local medicine stocks. Nonetheless, most medical facilities in the area are commercial, which restricts access for socially vulnerable population groups. In summary, despite the existence of certain life-support nodes, the functional layer in neighbourhood No. 1 remains vulnerable. The available infrastructure is capable of withstanding only short-term disruptions and is unable to cope with sustained crisis conditions.

Neighbourhood No. 2 (Northern Saltivka large-scale housing estate, Kharkiv) also demonstrates a critically low level of resilience. The area was heavily affected by active hostilities in 2022, which led to the partial loss of vital functional infrastructure. Even today, the neighbourhood remains a high-risk zone. Commercial facilities—such as supermarkets, a small market, and local stores—can meet only short-term needs and do not ensure sustainable functioning of the area during prolonged economic crises or

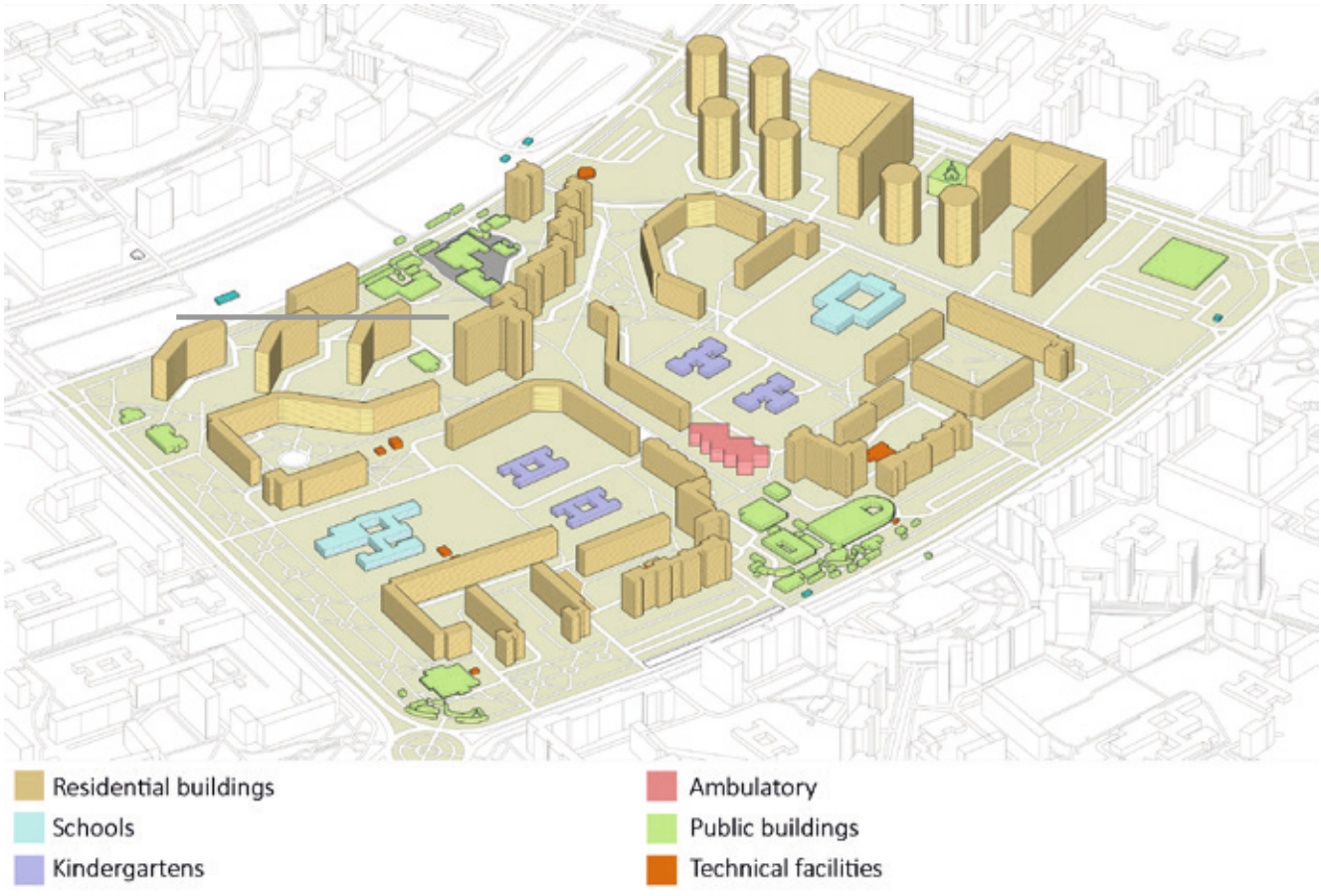

Fig. 16. Functional composition model of neighbourhoods No. 9/10 in Vygurivshchyna-Troieshchyna large-scale housing estate. DAAD, 2023-2024

supply disruptions. The main center of attraction is located outside both the neighbourhood and the entire Northern Saltivka housing estate—near the "Saltivska" metro station, where several large shopping centres and a major market are situated (approximately 2 km away). Most residents are employed outside the neighbourhood, while local employment opportunities are nearly nonexistent. This lack of economic diversification makes the area particularly vulnerable during economic downturns. Social and cultural infrastructure (clubs, community centres, libraries) is virtually absent. The only library in the area was closed in 2019. The neighbourhood has only one medical facility—a branch of a children's polyclinic—which was already insufficient before the war. Access to inpatient care is available only outside the neighbourhood. A few pharmacies remain operational, providing a minimal level of resilience in times of crisis, but their number and capacity are limited. Safety remains a critical issue. The neighbourhood lacks fully equipped underground shelters capable of protecting against military actions. This significantly undermines the safety of residents, especially under constant threat, as the area is regularly subjected to shelling. Existing shelters either do not function or are unsuitable for prolonged stays.

The analysis of the spatial layer "function" revealed a number of persistent issues. The main one is the low level of functional redundancy. Most neighbourhoods are equipped only with a basic set of functions, which is insufficient for maintaining resilience during prolonged crises. A second serious problem is the shortage of social and cultural infrastructure. The lack of public spaces, places for interaction, and inclusive services limits communities' ability to self-organise, reduces the level of social cohesion, and undermines local resilience.

An additional important factor that exacerbates the vulnerability of residential neighbourhoods is the complete absence of social housing. The mass privatisation of housing in Ukraine during the 1990s led to the concentration of the housing stock in the hands of private owners, without the establishment of effective mechanisms for collective management or the rapid repurposing of residential premises in crises. As a result, many apartments remain

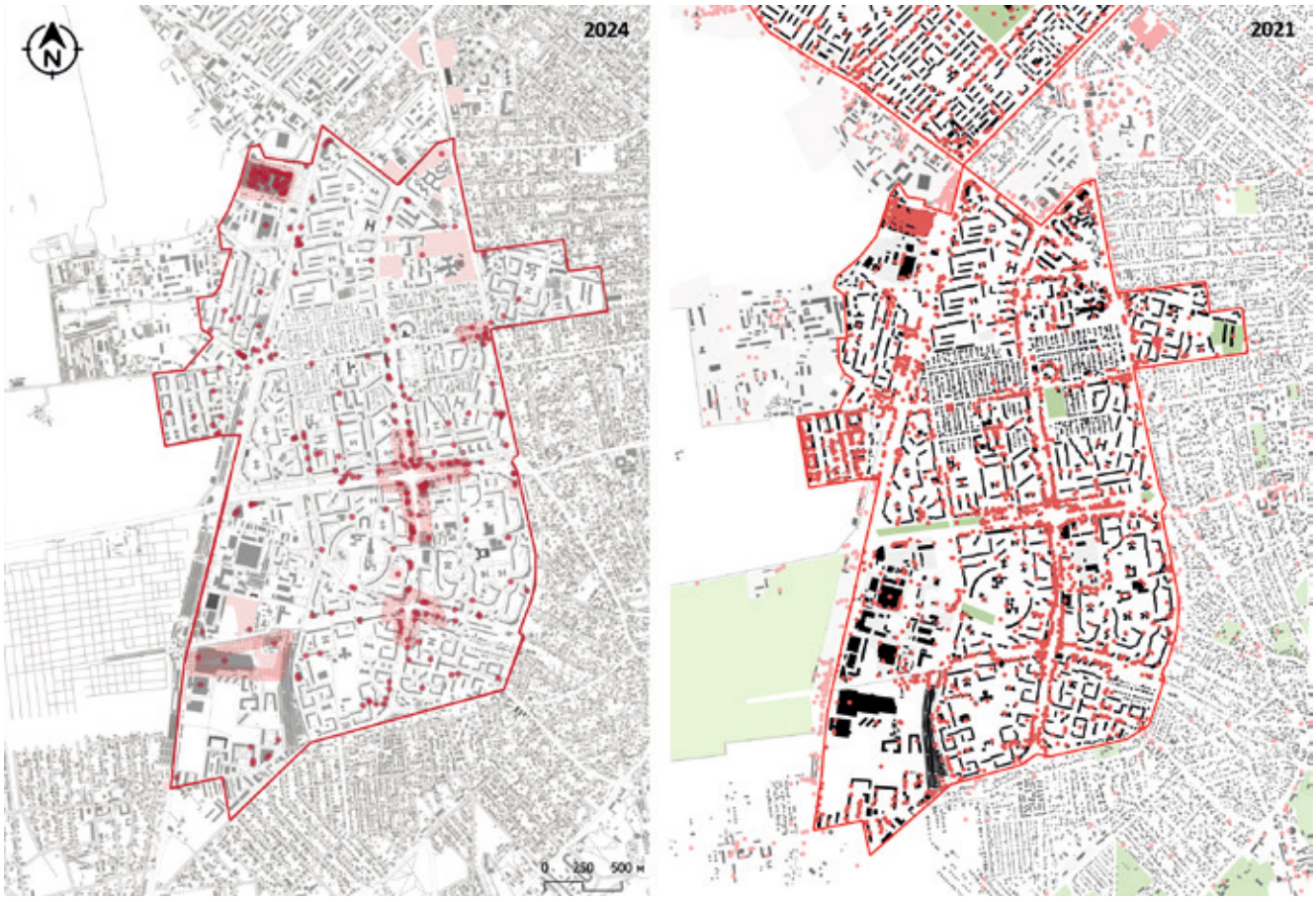

Fig. 17. Reduction of business outlets due to the war. Tairova large-scale housing estate. DAAD, 2023-2024

vacant, as their owners have left dangerous areas, and it is impossible to allocate these units to citizens affected by the war without the owners' consent. Moreover, under shelling conditions, there is an urgent need to relocate people from upper floors to safer lower levels. However, the absence of municipal tools for housing management makes such processes possible only informally, through personal agreements among acquaintances or relatives. This issue will persist into the post-war period. Without a radical revision of housing policy, Ukraine risks facing a large-scale housing management crisis after the war. Neighbourhoods that fail to restore their pre-war population levels will experience the phenomenon of half-empty buildings, despite the severe shortage of social housing.

Spatial Layer "Greenery/Public Spaces"

Neighbourhoods №9/10 are part of a large-scale residential estate where a cohesive green framework was never fully implemented. Although there is no integration with the citywide green infrastructure, the local green fragments within these areas remain relatively interconnected, except for some discontinuities. There is no full-fledged park space in the area. The only element performing this function is a long alley that connects two local markets. However, this alley serves mainly as a transit route rather than a recreational space, which limits the potential for diverse public leisure activities. The inner courtyards and the territories adjacent to educational institutions are insufficiently greened, despite the presence of certain functional elements, ranging from playgrounds to pet walking areas. The average courtyard size is around 1 hectare, and the high density of surrounding buildings and residents makes it difficult for residents to self-organise for the maintenance of these yard areas (Fig. 18).

The level of inclusivity in green spaces remains low. In addition, property rights issues and the lack of clear land demarcation complicate the distribution of responsibility for the maintenance of public spaces. The majority of the territory (51.6 ha) has an undefined legal status, while only 18.6 ha are municipally owned. This negatively affects the consistency and quality of green space maintenance. Green space maintenance is fragmented. Yard areas are typically cleaned, but inter-courtyard and public spaces are often neglected. Playground equipment and street furniture are outdated, and modernisation occurs rarely and only in selected areas. Under extreme weather conditions, such as heavy rain, heat waves, or storms, the vegetation in these neighbourhoods demonstrates low resilience. The green infrastructure struggles to perform basic protective functions, such as temperature reduction, air filtration, and moisture retention. Plants frequently suffer from water shortages and lack of care, and ecosystems do not recover after climatic stress. Green areas also contribute little to the preservation of biodiversity. Plantings exhibit low species diversity, and there is virtually no attention paid to protecting local biotypes. This makes these green spaces ineffective in supporting sustainable urban ecosystems. Moreover, green spaces do not provide adequate safety under constant threats, including armed conflict. There are no shelters or direct access to protective structures where residents could take refuge during emergencies such as military actions. An additional risk is posed by chaotic parking, which obstructs evacuation efforts and complicates crisis logistics (Fig.19).

The primary reason for the challenges in developing a high-quality green framework in the Vuzivsky neighbourhood (Tairova large-scale housing estate, Odesa) lies in the partial implementation of the original urban plan. The green corridors that were intended to connect the neighbourhood to the citywide water-green network and a large park were never completed. As a result, greenery in the area is fragmented and lacks a systemic structure. Of the 30.3 ha of open space, nearly 37% are classified as unarticulated areas — including courtyards, unused plots, and built-up zones. Only 6.6% is occupied by parks and green squares, which is critically insufficient given the high residential density. Areas adjacent to schools and kindergartens make up 21.9%, and green courtyards account for 24.4%. The underdeveloped system of public green spaces fails to effectively unite different social groups, which negatively impacts the social climate and resilience of local communities. The functional programming of courtyard spaces is monotonous, dominated by playgrounds and small rest zones for adults, and does not reflect the interests of all age and social groups. One significant, yet still unrealised, asset is the presence of a small botanical garden within the neighbourhood, which holds potential for both ecological and social functions. The issue of resilience to emergencies, including extreme weather events, remains highly relevant. The green areas are not adapted to climate change and are vulnerable to phenomena such as heavy rains, heatwaves, strong winds, and icing, which seriously affect plant health and long-term viability. Maintenance of green areas is irregular and selective. Municipal ownership is nearly absent (only 0.5 ha), and most of the territory lacks a defined legal status, making systematic management and responsibility allocation difficult. In addition, inclusivity remains a pressing concern: neither courtyards, nor alleys, nor adjacent public areas are adapted to meet the needs of various resident groups, including people with limited mobility and vulnerable populations. Shelters and protective structures are not inte-

grated into the neighbourhood's green infrastructure, which reduces the level of safety for residents in times of crisis or threat.

The planned green spaces of the Tavriiskyi large-scale housing estate in Kherson were not fully implemented by 1991. The green areas envisioned in the original project, which were meant to become full-fledged parks and public green spaces, were never created. While there is still some connection between the neighbourhood's greenery and other urban green areas, neighbourhood No. 1 is not fully integrated into the broader ecological context of the city and does not contribute to the development of effective ecosystems. A significant portion of the land is privately owned and inaccessible for public use.

Closed areas make up 27.4% of the neighbourhood. Out of 31 hectares of green space, the majority is occupied by inner courtyards (36.1%) and areas adjacent to schools and kindergartens (21.9%). Full-fledged parks and squares are absent within the boundaries of the neighbourhood. Functionally, green spaces are used in a limited way —

Fig. 18. *Green framework of the Vygurovshchyna-Troieshchyna large-scale housing estate and neighbourhoods №9/10. Planned and current. DAAD, 2023-2024*

mainly as children's and sports playgrounds, or small recreational zones. Most plants are in poor condition due to the war, lack of maintenance, and weak biomass. This leads to a loss of biodiversity in the local flora and fauna and reduces the neighbourhood's resilience to climate and environmental threats. Most green areas are primarily used as transit zones or have been repurposed as parking spaces for private vehicles. At the same time, before the war, there was a relatively high level of resident involvement in independently greening courtyard spaces in Kherson. The inclusivity of the neighbourhood's public green spaces is extremely low: they are not adapted to the needs of different population groups, including people with disabilities. During missile attacks or other emergencies, residents face difficulties in finding shelters, both underground and above-ground.

The state of greening in neighbourhood No. 2 (Northern Saltivka large-scale housing estate, Kharkiv) favourably differs from other neighbourhoods that were studied. Although the neighbourhood's greenery was not fully integrated into the green framework as originally planned, it contains a fully developed green corridors connected to external urban ecosystems. These corridors link the neighbourhood with the green infrastructure of the housing estate and the city. The quality of the green zones supports biodiversity — small wild animals and insects can be found here. Water features play a special role: the source of the Manzhosivka River with an underground spring, as well as a spring and marshland in the river's floodplain in neighbouring districts. The total area of green spaces in the neighbourhood is 36.5 hectares. A significant part of this area is occupied by inner courtyards (33.7%) and the plots adjacent to schools and kindergartens (23%). Closed areas account for less than 13%, which provides additional opportunities for flexible use of space in times of crisis. Before the war, green spaces offered functional diversity: there were designated zones for dog walking, pedestrian paths, sports and playgrounds, and areas for teenagers, adults, and the elderly. Despite the difficult military situation, public spaces in the neighbourhood continue to be used by residents in everyday life. They serve not only as transit routes but also as places for walking, short-term rest, and social interaction. At the same time, the lack of

Fig. 19. Chaotic parking in neighbourhood No. 9/10 hinders potential evacuation and access for emergency vehicles. DAAD, 2023-2024

a clear functional structure for green spaces and blurred ownership boundaries reduces the overall resilience of the environment. The areas around kindergartens, schools, and clinics have formalised boundaries and assigned caretakers, while courtyard spaces often lack clear identification, which leads to the formation of neglected plots. The inclusivity of public spaces remains insufficient: most areas are not adapted for people with limited mobility. The level of safety in public spaces in the context of military threats also remains low: there are no exits from green zones to shelter facilities. There are reserve plots in the neighbourhood that, with proper planning, can be integrated into the existing green infrastructure or used for the placement of small alternative energy installations and facilities.

The analysis of the "green public spaces" spatial layer showed that none of the neighbourhoods fully meet the criteria for sustainable green infrastructure. Common issues include insufficient integration of green areas into the city's ecological and social systems, lack of organised and systematic maintenance of green spaces, and a low level of inclusivity. The most resilient is neighbourhood No. 2 in Kharkiv, which is due to its proximity to natural water-green sites and existing connections with natural ecosystems. The most unfavourable situation is observed in the Vuzivsky neighbourhood in Odesa, where public space is highly fragmented, with underdeveloped and disconnected elements of the green framework.

Spatial Layer "Climate Adaptation"

Neighbourhood No. 9/10 (Vygurivshchyna-Troieshchyna large-scale housing estate, Kyiv) serves as an example of an area with moderately stable climatic characteristics but a significant load on the climate system due to urbanisation. It is located in a flat area with a moderately continental climate and warm summers (type Dfb) at an elevation of 102–103 meters above sea level. The risk of flooding due to global warming is absent. Historically, the neighbourhood has experienced extreme weather events: abnormal heat (2017), heavy rains (2020), floods (1970, 2004, 2023), snow drifts (2021), and frequent storms with wind gusts reaching up to 20 m/s. However, there have been no catastrophic events such as natural disasters resulting in loss of life or a sharp deterioration in public health. These events have not caused direct destruction of buildings or infrastructure. While the consequences of such events remain reversible for now, the lack of resilient spatial planning may lead to a critical situation in the future. Overheating issues are partially mitigated by trees, but the density of green vegetation is critically low. Plantings are extremely sparse and unevenly distributed, failing to create significant shaded areas or effectively reduce overheating. Currently, the number of trees and shrubs is insufficient. Tree damage from storms is regularly observed, yet measures such as pruning old trees and planting new ones have proven ineffective. There are no green roofs or green walls in the neighbourhood, and automatic irrigation systems are absent. There are no projects for diverse greening that incorporate native plant species, seasonal planning, or elements of ecosystem-based design. The only water feature within the neighbourhood is a water well (buvet), which has virtually no impact on the natural cooling of the area. The situation is worsened by the predominance of asphalt as the main surface material and the presence of dark-colored facades on some residential buildings. High surface temperatures in summer and a lack of shade in public spaces can negatively affect the physical and mental well-being of vulnerable groups. The drainage system is in poor condition and cannot cope with heavy rainfall. During major downpours, water flows through the streets, negatively affecting soil conditions and vegetation (Fig. 20).

The Vuzivsky neighbourhood (Tairova large-scale housing estate, Odesa) is characterised by harsher climatic conditions typical of the BSk semi-arid climate zone, marked by sharp temperature fluctuations and prolonged dry periods. The proximity of the Black Sea (approximately 1.6 km) exerts a stabilising influence on the local climate. However, dense urban development and unstructured landscaping result in areas with limited air circulation and significant heat accumulation. The neighbourhood lacks green corridors that could connect various parts of the area, thereby enhancing airflow and facilitating the migration of beneficial species. The elevation ranges from 42 to 48 meters above sea level, which eliminates the risk of flooding associated with global sea-level rise. Nonetheless, the area is subject to a high risk of local flooding due to elevated groundwater levels, as evidenced by frequent basement inundations. Several climate anomalies have been documented in recent years, including heatwaves (2017), dust storms (2019, 2020), recurrent low-intensity seismic activity, annual droughts, freezing rain, and icing events. The neighbourhood contains no water features, which is particularly problematic during frequent summer overheating episodes, as such elements could otherwise function as local climate buffers. While inner courtyards are generally greened, providing some mitigation of the high temperatures characteristic of Odesa's southern climate, the overall quality of vegetation is unsatisfactory. There are no automatic irrigation systems, and green infrastructure elements such as green walls or rooftop vegetation are absent. Green spaces are typically maintained

by residents on an informal basis and are composed of lawns, individual trees, and flower beds near building entrances. However, under increasingly frequent dust storm conditions, the existing vegetation proves inadequate for effective air filtration. The majority of the neighbourhood's surface area is impermeable, primarily consisting of asphalt with limited paving using tiles. This increases pressure on the stormwater drainage system and significantly heightens the risk of localised flooding. Icing and snowfall regularly disrupt the electricity supply, including through the breakage of power lines, and there are no dedicated protective measures in place to address these hazards.

Neighbourhood No.1 (Tavriiskyi large-scale housing estate, Kherson) is located in the same climate zone as the Vuzivsky neighbourhood and faces similar challenges. The area is subjected annually to dust storms, droughts, hailstorms, and squalls. An additional threat is posed by winter ice storms, which frequently cause power line failures. Although the proximity to the Black Sea (1.6 km) and nearby rivers (3.5 to 5 km) offers potentially favourable conditions for climate regulation, the neighbourhood suffers from weak greening — the number of green plantings is insufficient for effective climate control. Green areas are concentrated in isolated spots and are primarily represented by groups of trees and shrubs planted over 30 years ago. Dust-laden air masses freely enter the courtyards due to inadequate vegetation barriers. There are no automatic irrigation systems in place. Biodiversity is extremely low, with a limited variety of plant species used, most of which have proven sensitive to the droughts and storms typical of the area. There is a critical shortage of shade in the courtyards, and no water features are present that could provide thermoregulation and cooling during hot periods. Vertical greening and rooftop landscaping are also absent. Regular shelling of the neighbourhood has a serious negative impact on the condition of green spaces. Trees, shrubs, and lawns are damaged; the soil becomes compacted and degraded, which worsens conditions for plant growth. The structure of green areas is disrupted, reducing their ecological effectiveness, including their ability to purify air, regulate the microclimate, and lower noise levels. Moreover, damaged or dead vegetation poses additional safety risks for residents. Ongoing destruction hinders scheduled maintenance and the restoration of green spaces, weakening the urban environment's resilience in the long term. A systemic negative environmental effect was caused by the disaster that followed the destruction of the Kakhovka Hydroelectric Power Station by Russia in 2023, when a massive volume of water flooded the low-lying areas of the city and destroyed established ecosystems (Borniak & Kryvochyzha, 2023).

Neighbourhood No.2 (Northern Saltivka large-scale housing estate, Kharkiv) demonstrated the highest climate resilience among those reviewed, although its resilience level was assessed as moderate. The neighbourhood is located in a moderately continental climate zone (Dfb type). It is exposed to droughts and squalls; however, these natural phenomena do not cause destruction or pose a direct threat to human life and health. Elevation levels range from 122 to 151 meters. The complex terrain, with significant elevation differences, facilitates natural water drainage. However, uncontrolled erosion of the fertile topsoil degrades its quality and adversely affects vegetation. The situation is further worsened by the poor state of the stormwater drainage system and a lack of permeable surfaces: asphalt dominates the neighbourhood, while tiles are used only near water bodies. In terms of climate change resilience, the neighbourhood exhibits several positive features. High-rise buildings with predominantly light-colored facades help reduce thermal load during the summer months. The white surfaces of building facades reflect solar radiation, preventing overheating. Airflow within the neighbourhood is unobstructed due to the relatively large distance between buildings. The neighbourhood directly borders a water body — the source of the Manyosivka River and a spring, around which a green recreational area is established. This contributes to the creation of a favourable microclimate for the residential buildings located nearby. It is also important to note that the main green corridors in the area are historically established forest belts that used to divide fields and pastures. These corridors are better landscaped than the vegetation planted after the development of the residential complex. Compared to other areas, this neighbourhood is less prone to overheating during summer periods. Military activity has harmed the state of green infrastructure; however, this effect is localised and does not exert a systemic influence.

The analysis of the "climate adaptation" spatial layer across four neighbourhoods revealed an absence of specific measures aimed at mitigating the consequences of climate change. Nevertheless, the situation is not considered critical due to favourable geographic conditions, climate, and natural zones, which do not present risks of large-scale natural disasters, as well as the local ecosystems' ability to regenerate naturally.

Spatial layer "Critical Infrastructure"

Historically, the critical infrastructure of residential neighbourhoods was designed within centralised planning frameworks, characterised by a high degree of standardisation. Its peak development occurred during the Soviet period, when priority was given to the speed of construction and the scale

of coverage, rather than to the quality, energy efficiency, or durability of materials. As a result, poor construction quality, cost-cutting measures, the lack of timely repairs, and inefficient operational oversight led to the rapid deterioration and failure of critical infrastructure systems [169].

Already at the beginning of the post-Soviet period, interruptions in water and electricity supply began to occur, along with frequent accidents and pipeline bursts caused by the deterioration of materials and the absence of a modernisation system. Despite the growing need for reconstruction and adaptation, there were no investments in the comprehensive modernisation of these systems. The active construction of new residential districts, shopping and entertainment centres, and other commercial developments after 2000 placed additional pressure on the existing critical infrastructure.

Following the onset of the full-scale war and targeted Russian strikes on infrastructure, the situation became critical. The destruction caused by shelling turned into a catastrophe for many cities, especially those located near the front line (Soldak et al., 2024). One approach to stabilising the situation has been to reassess centralised systems and initiate the gradual decentralisation and autonomization of critical infrastructure (International Energy Agency, 2024). The decentralisation of governance and the empowerment of local communities played an important role, enabling more effective responses to local crises and ensuring access to necessities such as heat, electricity, and water, even under critical wartime conditions (Rabinovych, 2023; Brovko, 2024).

Currently, the critical infrastructure in all the studied neighbourhoods represents a relatively stable but outdated provision model. Its resilience is rated as low, and the organisation of critical infrastructure systems remains vulnerable. Private initiatives to install personal generators within neighbourhoods do not solve the issue at the community-wide level but rather create localised resilience hubs that are generally only accessible to more affluent residents. The level of decentralisation of critical infrastructure remains low. Almost all systems rely on centralised sources: electricity, water, heating, internet, and gas. There is no possibility for local management, resource

Fig. 20. Condition of green spaces in public areas in Ukrainian neighbourhoods. Collage by Nadiia Antonenko

redistribution, or even autonomous operation of individual building clusters. This makes neighbourhoods dependent on citywide decisions, limits the capacity for local response, and increases recovery times after damage.

Electricity supply in all neighbourhoods is centralised, with transformer substations servicing several residential and public buildings. Since the beginning of the war, resilience points equipped with generators have been set up in the neighbourhoods, enabling residents to charge mobile devices, heat water, and use electrical appliances during critical periods. This has somewhat improved resilience during large-scale power outages; however, the current number of such points is insufficient. The existing electrification system of the neighbourhoods is inefficient. The centralised structure of the energy system makes it vulnerable to massive attacks. A gradual transition to a decentralised model with distributed energy resources is gradually improving system resilience. Modular microgrids can provide an autonomous power supply to critical infrastructure facilities such as hospitals, schools, and military sites, even if the main grid is damaged. However, decentralised energy sources are absent in the examined neighbourhoods.

Internet access is provided by local commercial providers, which is typical for most Ukrainian neighbourhoods. While this model is relatively stable, it does not ensure resilience against cyber threats or network destruction. Satellite internet is used privately in these areas.

Radio communication operates through state radio broadcasting, which delivers essential information during critical situations. However, many residents do not use radio receivers. Cable television is also available.

Water supply and wastewater systems are centralised in all neighbourhoods. Some neighbourhoods have water reservoirs for firefighting needs (e.g., in the Vuzivsky neighbourhood of Odesa). In Kharkiv, a local body of water can serve as an additional reservoir, and natural springs are used for drinking water. In neighbourhood No.9/10 in Kyiv, there is one spring water pump room, and five more are located within walking distance in adjacent districts. Water reserves are also stored in underground shelters, but these reserves are insufficient to meet the needs of all residents.

All neighbourhoods, except for neighbourhood No.9/10 in Kyiv, are connected to the gas grid. On one hand, this increases the vulnerability of buildings during fires and attacks, but on the other hand, it allows for cooking, heating water, and space heating when electric systems are damaged. To some extent, barbecue areas or outdoor kitchens can be considered small alternative zones for food preparation and water heating. Such kitchens were spontaneously organised in the most affected neighbourhoods of Kherson and Kharkiv.

Heating systems in the buildings are centralised and lack supplementary sources, making neighbourhoods dependent on mainline utility networks, especially when there is significant depopulation and partial building occupancy (as seen in Kherson and Kharkiv). Providing centralised heating to buildings with only 30% occupancy is extremely inefficient. The situation is worsened by fragmented efforts to improve building energy efficiency. Apartment privatisation, large facade areas of high-rise buildings, and the low income levels of residents hinder the reduction of heating energy consumption, despite the development of municipal and national programs promoting energy-efficient transitions.

The condition of stormwater drainage systems is unsatisfactory across all neighbourhoods.The emergency alert system has been developed over three years of war, but attacks often occur faster than the system can respond.

Redundancy and reserve capacities within the systems are virtually nonexistent. Even when alternative sources are present, they cannot replace the main infrastructure and serve only as temporary solutions. This critically undermines the neighbourhoods' ability to function in the event of damage or outages of primary systems. The absence of reserves increases vulnerability: even a short-term disruption can destabilise the entire social system. The critical infrastructure of the neighbourhood requires thorough inventorying, planning, and phased implementation of new systems. At present, despite the ongoing military threats, municipal services manage to deal with emergencies relatively promptly, but there is no systemic modernisation—only spot replacements of damaged components. Under wartime conditions, radical technological upgrades or the construction of new infrastructure are practically impossible.

Spatial Layer "Identity"

The resilience of the spatial layer of "identity" in neighbourhoods manifests as a complex phenomenon where cultural, social, and political transformations intersect with everyday practices and are reflected in the physical environment. Initially, the identity of neighbourhoods, embedded in the urban planning logic of the Soviet era, was based on a clear compositional structure, an aspiration for expressive façade solutions, the active integration of artistic elements into the everyday urban environment, a diversity of landscaping forms, and the creation of unique architectural accents. Architects of the 1980s sought to

give each courtyard and building a recognisable character to individualise residential development and create a cohesive environmental image. However, these ambitions were diluted in practice due to budget cuts in landscaping and greening efforts (Mysak, 2018). Since the 1990s, this image has gradually begun to change. The first to transform were the ideological elements of identity: Soviet symbols, bas-reliefs, and monumental compositions disappeared, often destroyed through acts of vandalism. Metal art objects and elements of urban infrastructure were actively sold for scrap.

Fig. 21. Visual expressions of spatial identity in neighbourhoods. Collage by Nadiia Antonenko.

Later, these processes were accompanied by state-led initiatives of decommunization, de-Sovietization, and de-imperialization of urban spaces (Golikov, 2020). At the same time, new informal forms of environmental marking emerged: graffiti appeared on the streets, alongside signs of youth gang activity and advertisements for drug couriers. Commercialisation processes took hold: the repurposing of apartments, façade insulation, balcony glazing, and construction of extensions significantly altered the original appearance of residential buildings.

In later stages, new elements of spatial identity began to take shape: murals, small architectural forms, and commemorative inscriptions appeared in the neighbourhoods (Provotar et al., 2021). Since 2014, memorials dedicated to the heroes of the Maidan—the Heavenly Hundred—as well as to the heroes of the Russian-Ukrainian war, have been integrated into the urban landscape.

In addition to the detailed analysis of the resilience of each spatial layer, the study allowed for a deeper exploration of the impact of various types of threats on the spatial characteristics of residential buildings of this morphological type. In particular, the analysis identified the potential and limitations of the tools used in urban planning, urban design, and architecture, in the context of their ability to contribute to either enhancing or, conversely, reducing the resilience of the urban environment.

The diagram demonstrates the overall vulnerability to risks of the spatial characteristics of the morphological type of 1980s neighbourhoods (gray bars) and the current vulnerability to risks of each of the Ukrainian and German neighbourhoods analyzed (lines of the colored graphs) (Fig. 22). These evaluations reflect cases of negative impact on resilience caused by factors related to urban planning expertise. The chart also presents specific answers with negative values, allowing an assessment of the vulnerability of spatial characteristics to different types of threats.

According to the obtained results, the greatest impact on the physical parameters of spatial resilience is made by the following threats (in descending order of significance): armed conflict in the country, extreme weather events, wear and damage to critical infrastructure, lack of economic opportunities, power outages, natural aging of the housing stock, loss of biodiversity and destruction of ecosystems, as well as poverty.

Identifying the spectrum of threats that have the greatest impact on the resilience of the urban fabric allows for more well-founded future development scenarios. These data can serve as a starting point for making strategic decisions aimed at strengthening the resilience of the urban environment and forming resilient spaces in conditions of uncertainty and multilayered risks.

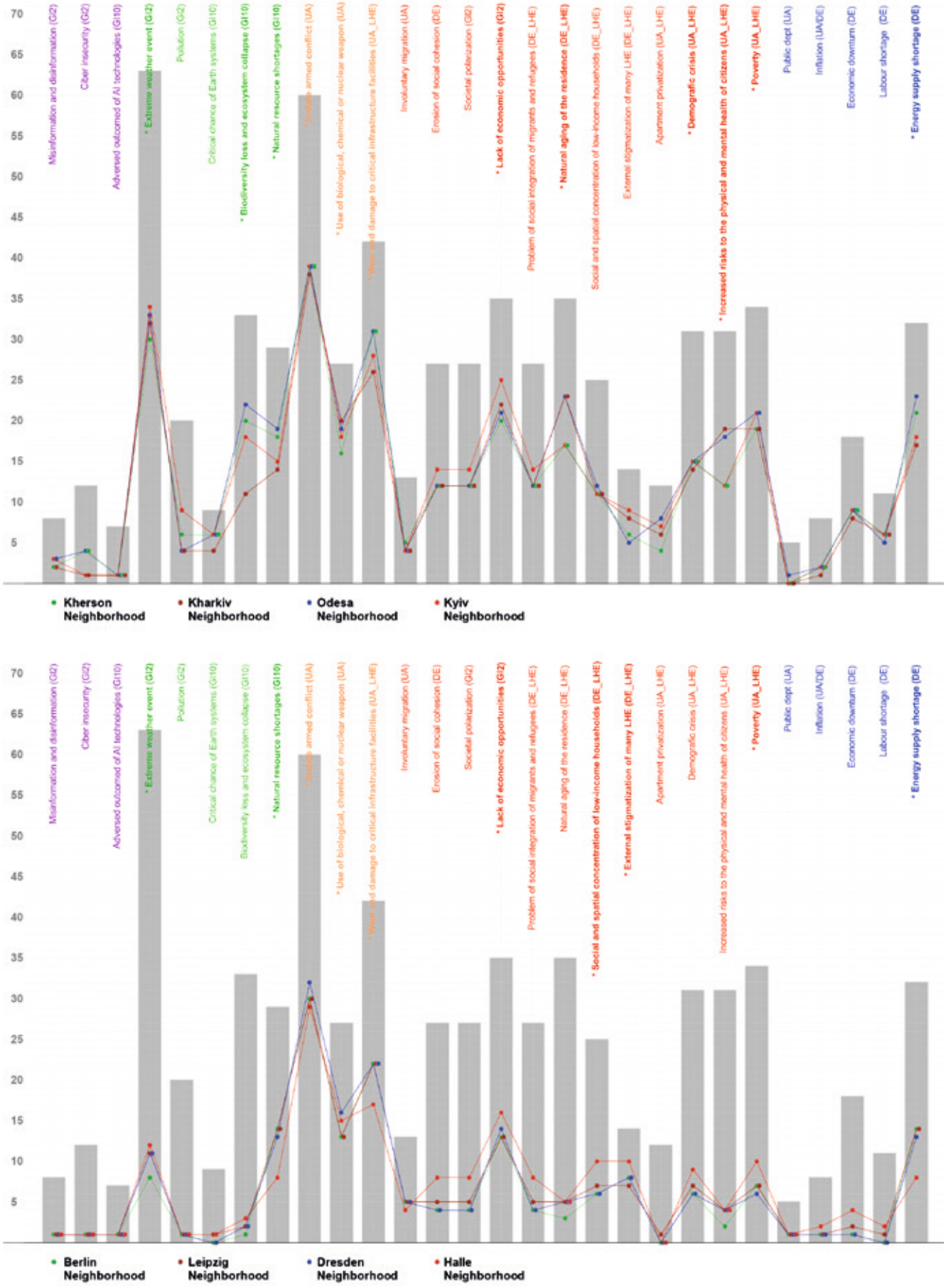

Fig. 22. Overall vulnerability to risks of the spatial characteristics of 1980s neighbourhoods. Diagram by Nadiia Antonenko

7 Spatial experience of large-scale housing estates in Germany for Ukraine

Large-scale housing estates (Großwohnsiedlungen) in Eastern Germany have been the subject of research and practical experiments since the early 1990s. The scientific interest has encompassed both historical and contemporary aspects of urban planning, social structure, governance, and the resilience of such areas. Particular attention is paid to studies analysing large-scale housing estates in terms of the influence of various types of threats and their ability to perceive and resist these threats (Altrock et al., 2022; Kabisch, 2024). Contemporary research is also focused on developing strategies to enhance the capacity of large-scale housing estates to adapt to external stresses and crises, including through spatial-architectural solutions (Altrock et al., 2018).

Unlike Ukraine, where the primary and defining threat to neighbourhoods is full-scale war, in Germany, large-scale housing estates face a different spectrum of risks, among which the most critical are climate, energy, economic, and social challenges.

Climate threats are becoming increasingly tangible. The rise in extreme weather events—prolonged droughts, heatwaves, intense precipitation—places additional strain on urban infrastructure and engineering networks. Areas with high building density, a shortage of green spaces, and water bodies are particularly vulnerable, where the need for climate adaptation calls for additional spatial and architectural solutions.

Economic challenges also remain pressing. In the neighbourhoods formed during the GDR period, despite the implementation of numerous regional development programs, issues such as demographic ageing, youth migration, and limited economic diversification continue to persist. Structural changes in the economy have not always been accompanied by the creation of sustainable alternatives to traditional industries. This reduces the investment attractiveness of certain areas, weakens the local labour market, and amplifies the socio-economic vulnerability of neighbourhoods in large-scale housing estates.

One of the key social issues in residential districts is demographic ageing and the rise of poverty. Some neighbourhoods become spaces of concentration for low-income, poorly educated groups and migrants, reducing the level of civic participation and hindering social integration. They also face an increase in crime, violence, and the spread of drugs.

In the context of modern geopolitical instability, especially after the start of the full-scale war in Ukraine, discussions in Germany have intensified about rethinking the readiness of urban neighbourhoods for potential military threats. Although Germany does not face direct military impact, experts point to the vulnerability of urban infrastructure, especially in multi-story districts built during the GDR period, to potential crises, including military conflicts (Sänger, 2024). A key aspect of the discussion is the insufficient integration of military infrastructure into urban space. After the Cold War, many military sites were removed from cities, decreasing the visibility and presence of armed forces in everyday civilian life. However, in light of current threats, there is a need to return military structures to cities to ensure safety and enhance resilience. Experts also emphasise the importance of developing the concept of "Total Defence"—a comprehensive defence including both military and civilian components. This requires not only modernising the armed forces but also strengthening civil defence, including warning systems, medical services, and life-supporting infrastructure. However, implementation faces several obstacles, including bureaucratic challenges, lack of funding, and the need for coordination across government levels.

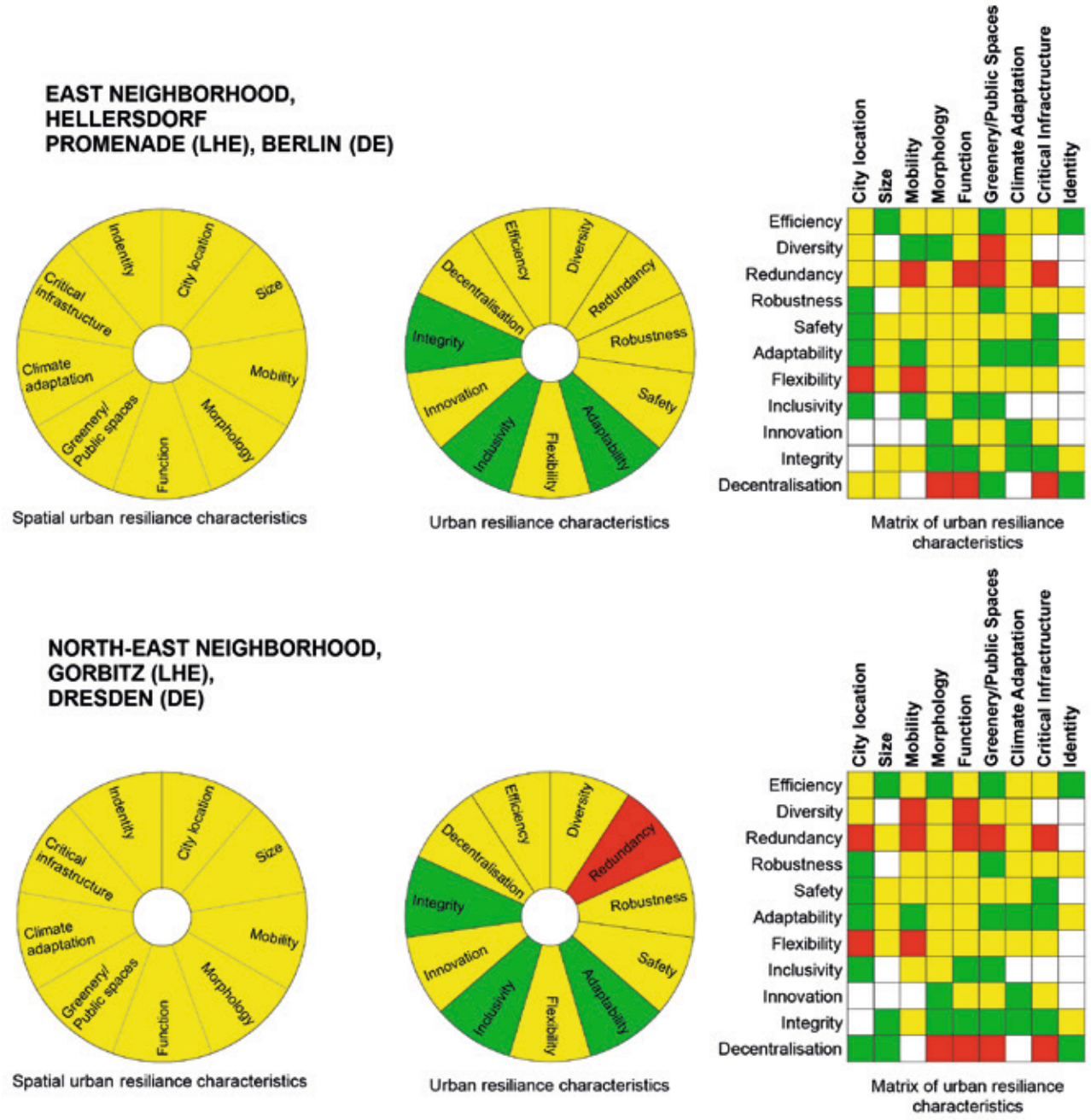

Fig. 23. *Sectoral diagram of spatial urban resilience. Sectoral diagram of resilience characteristics assessment. Matrix for assessing spatial urban resilience. German neighbourhoods (Berlin, Dresden). Developed by Nadiia Antonenko*

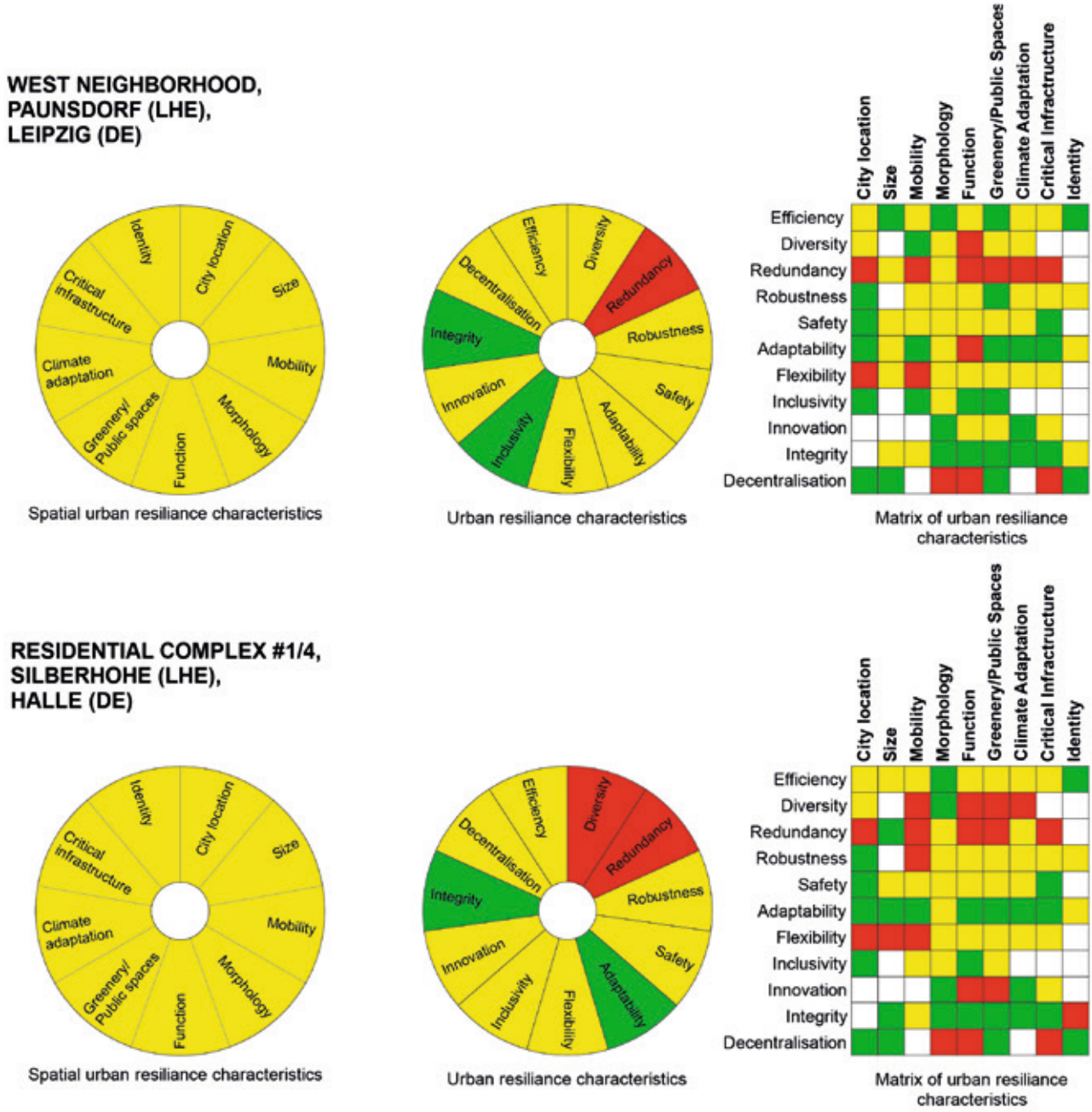

Fig. 24. *Sectoral diagram of spatial urban resilience. Sectoral diagram of resilience characteristics assessment. Matrix for assessing spatial urban resilience. German neighbourhoods (Leipzig, Halle). Developed by Nadiia Antonenko*

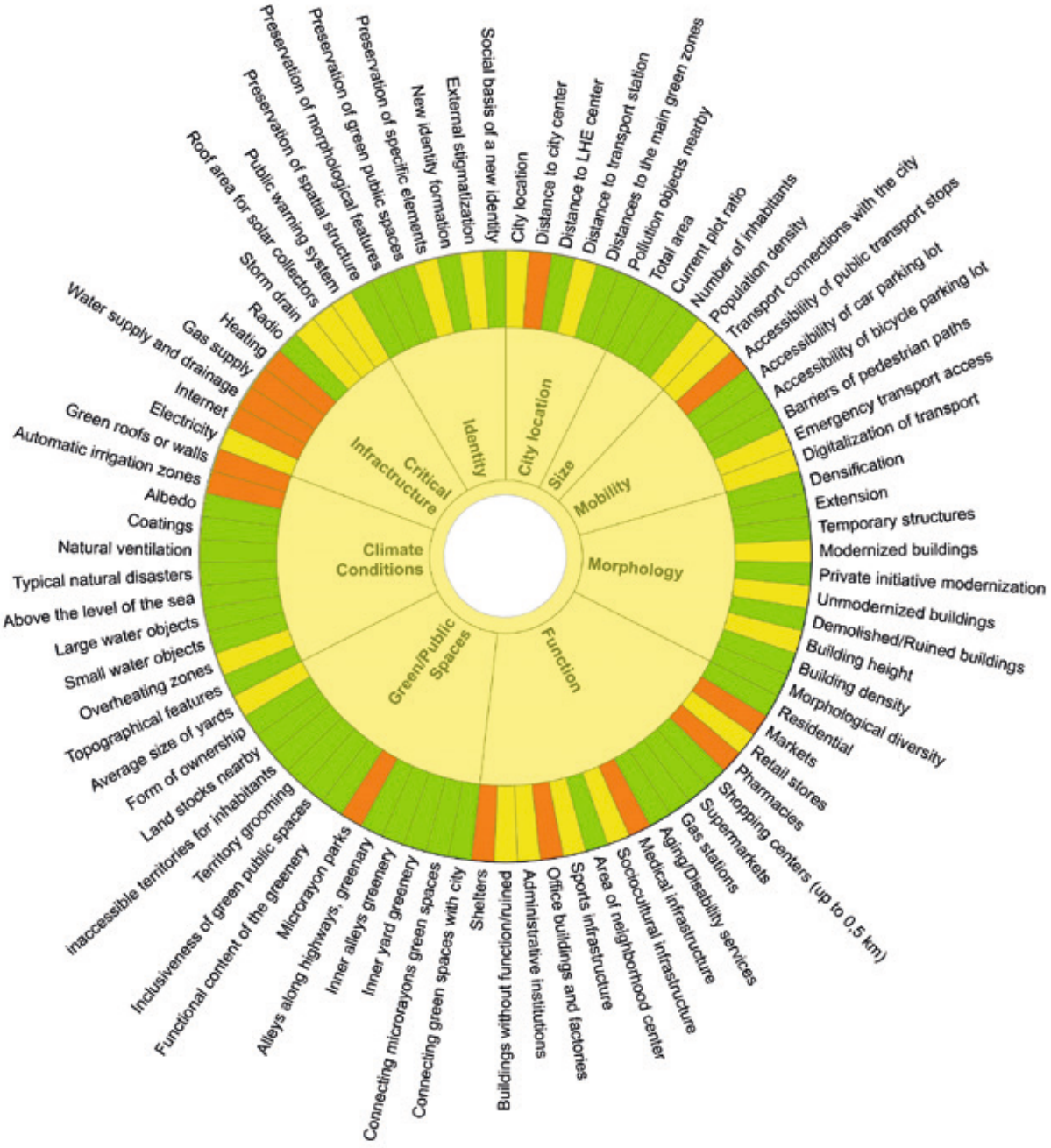

Fig. 25. *Spatial Resilience of Eastern neighbourhood in Hellersdorf Promenade. Sectoral diagram of spatial resilience characteristics. Developed by Nadiia Antonenko*

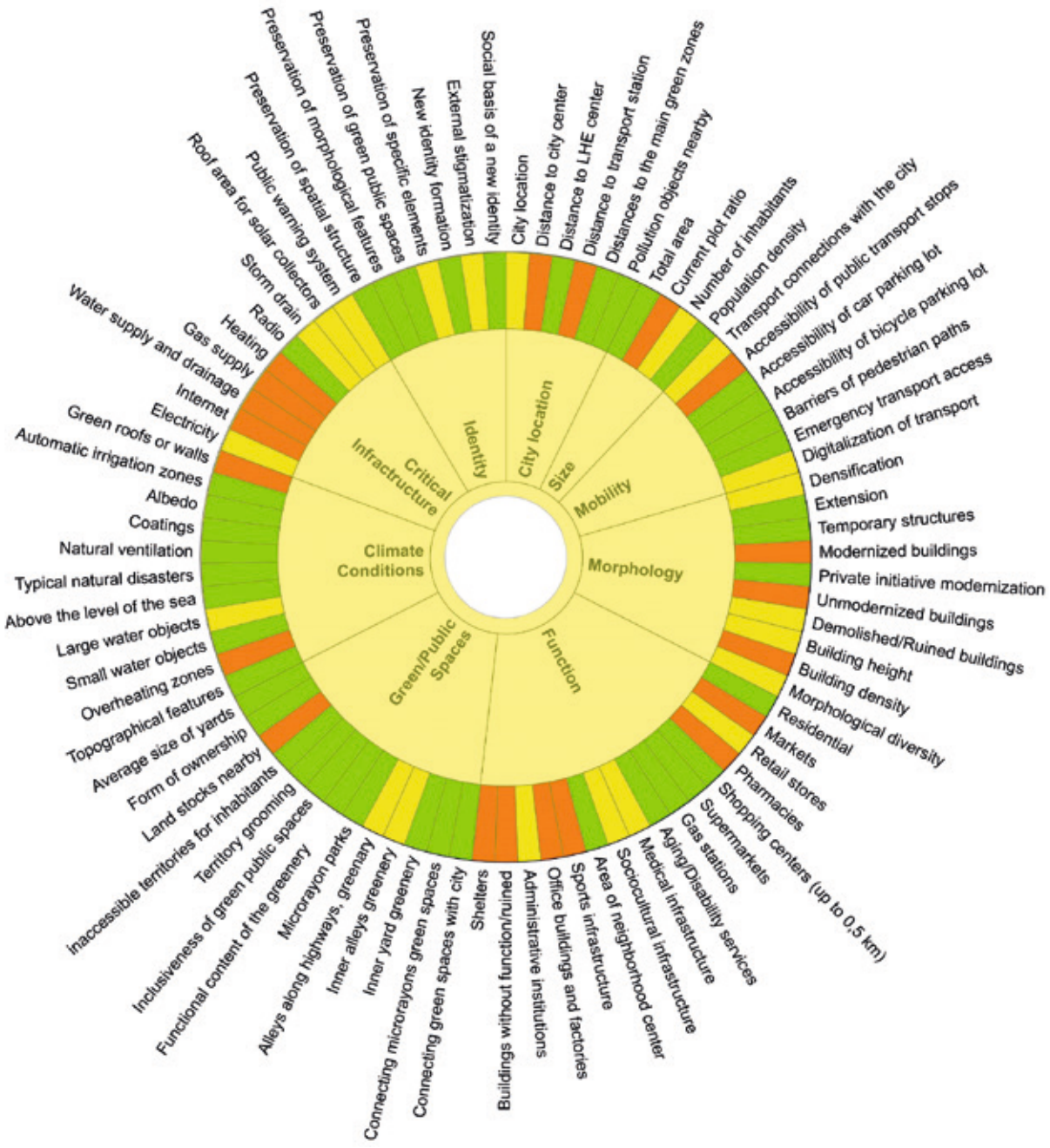

Fig. 26. *Spatial Resilience of North-Eastern neighbourhood in Neu-Gorbitz, Dresden. Sectoral diagram of spatial resilience characteristics. Developed by Nadiia Antonenko*

Energy vulnerability is another important risk factor, exacerbated by the war in Ukraine. Reduced energy supplies, rising prices, and the need for a faster transition to renewables exert pressure on the entire system supplying residential areas. The old housing stock, not adapted to modern energy efficiency standards, becomes burdensome for both residents and urban budgets. The energy transformation requires significant investment and strategic rethinking of the spatial structure.

For the analysis of spatial resilience in German neighbourhoods from the 1980s, the same methodology was used as for Ukrainian neighbourhoods (Fig. 23–28). This approach enabled a detailed layer-by-layer comparative analysis, identifying key spatial characteristics that made German neighbourhoods more resilient to various threats. The analysis highlighted the importance of considering local conditions and context when designing residential areas, helping to identify the most successful elements in the

German neighbourhoods. Additionally, recommendations were made regarding technologies and approaches to implement in Ukrainian cities facing new potential threats such as climate change, economic instability, and urban challenges. The study also identified specific characteristics of Ukrainian neighbourhoods to consider in Germany's urban planning.

Spatial layer "Size"

German large-scale housing estates were originally conceived as medium-sized settlements (up to 100,000 inhabitants), though most neighbourhoods typically ranged from 3,000 to 7,000 residents. This scale was seen as optimal for organising daily life, with essential services—schools,

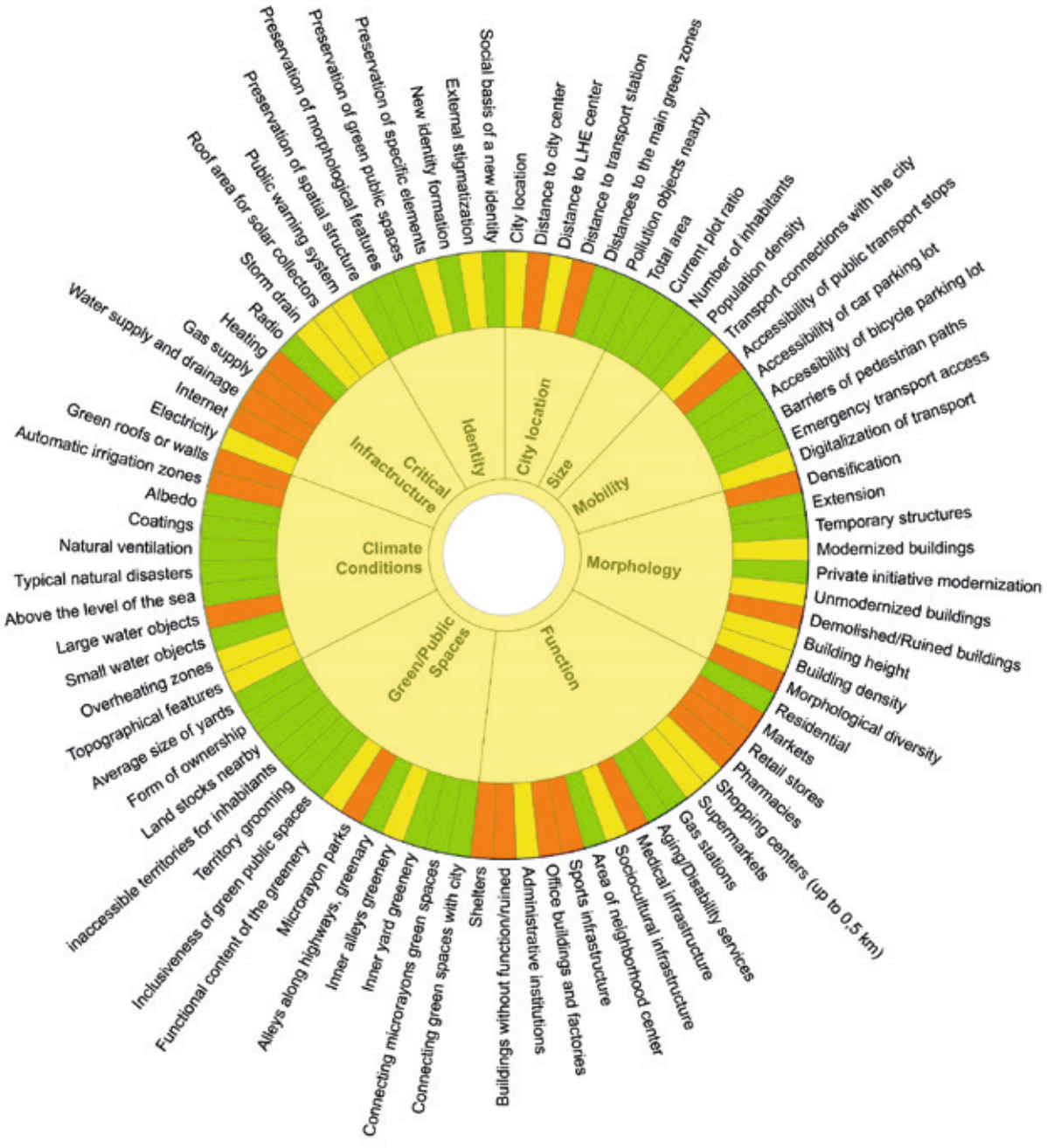

Fig. 27. *Spatial Resilience of West neighbourhood, Paunsdorf, Leipzig. Sectoral diagram of spatial resilience characteristics. Developed by Nadiia Antonenko*

kindergartens, shops, public spaces, and transport stops—within walking distance. Such planning aligned with the principles of functional zoning and the "city of short distances" (Stadt der kurzen Wege). The analysis of German neighbourhoods shows that all studied cases meet spatial resilience criteria to varying degrees. The most resilient examples, such as the Eastern neighbourhood in Hellersdorf Promenade and Neu-Paunsdorf, feature optimal areas, structures, and populations within the recommended range. However, Hellersdorf's high population density, while promoting compactness, may strain infrastructure under extreme conditions. In contrast, areas like the North-Eastern neighbourhood in Neu-Gorbitz and Residential Complex No. 1/4 in Silberhöhe are marked by lower densities and smaller populations, reducing economic resilience but enhancing spatial flexibility and adaptability to epidemiological and climate-related risks.

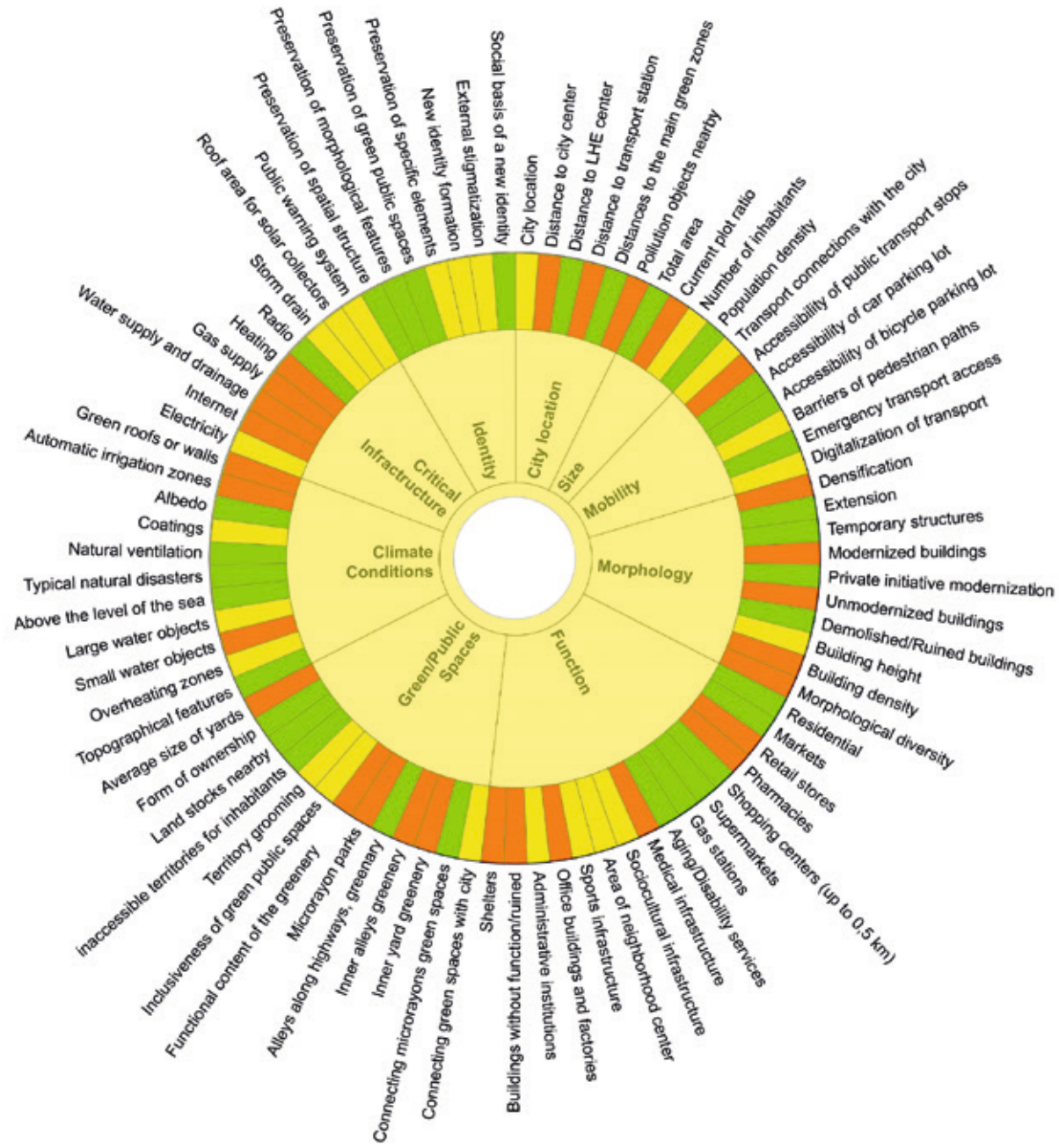

Fig. 28. *Spatial Resilience of Residential Complex No. 1/4 in Silberhöhe, Halle. Sectoral diagram of spatial resilience characteristics. Developed by Nadiia Antonenko*

Recommendations for Post-War Regeneration of Ukrainian neighbourhoods (Spatial layer "Size"):

- Optimise neighbourhood size by dividing larger areas into smaller, manageable units with moderate compactness and balanced density.
- Limit residential neighbourhood areas to 20–30 hectares with populations between 3,000 and 7,000 people, promoting resilient infrastructure and community ties.
- Develop neighbourhoods as autonomous spatial units with clear boundaries and the capacity to function independently during crises.
- Ensure the presence of reserve spaces suitable for emergency infrastructure and autonomous systems without oversizing.
- Create a hierarchy of spaces (intra-block, semi-private, public), ensuring key infrastructure is walkable.
- Enable incremental development to allow phased upgrades without requiring complete reconstruction—an approach vital under post-war resource constraints.

Spatial layer "City location"

Large-scale housing estates in Germany from the 1980s were primarily developed on undeveloped agricultural land or the sites of former villages, similar to practices in Ukraine. These areas often formed separate urban districts or satellite settlements, functioning as relatively autonomous units within the broader urban structure. Simultaneously, central city areas underwent reconstruction using standardised industrial solutions, which led to dense development and modernisation of the existing housing stock.

After 1989, these districts experienced a gradual spatial transformation. In the early phase, their structure remained largely stable, with only minor changes. Over time, regionalisation intensified, especially in larger cities: suburban areas were incorporated into city boundaries, and formerly peripheral neighbourhoods became integrated into the expanding urban fabric. In smaller cities, however, large-scale housing estates often remained on the periphery, limiting their integration into the broader urban system.

In terms of spatial resilience, the Western neighbourhood in Neu-Paunsdorf (Leipzig) and the North-Eastern neighbourhood in Neu-Gorbitz (Dresden) show the highest levels of conformity to optimal parameters. Both are situated at moderate distances from city centres, have well-developed transport infrastructure, and are surrounded by green zones with low ecological risk. Their location ensures everyday access to urban functions and supports adaptability in crises. The integration into the urban structure, combined with green buffer zones, enhances their resilience to ecological and climate challenges. Nonetheless, these neighbourhoods also exhibit some vulnerabilities, such as limited infrastructure redundancy, constrained administrative flexibility, and economic dependence on external centres.

By contrast, the Eastern neighbourhood in Hellersdorf Promenade (Berlin) and Residential Complex No. 1/4 in Silberhöhe (Halle) display less resilient characteristics. Both are located farther from city centres, which reduces spatial connectivity despite favourable recreational environments. Their long-term resilience depends on improved transportation access and strengthened local autonomy.

Based on the German experience, Ukrainian neighbourhoods can adopt several spatial and institutional solutions that significantly improve their resilience in the "city location" layer. At the same time, German urban planners should pay attention to mechanisms for enhancing the resilience of this spatial layer, taking into account the experience of Ukrainian residential neighbourhoods:

Recommendations for Post-War Regeneration of Ukrainian neighbourhoods	Recommendations for German neighbourhoods
• To form full-fledged local subcenters, which include retail, domestic services, recreational areas, and administrative functions. This will help reduce the daily dependence on trips to the city centre, making everyday life independent of external transport infrastructure. • To develop neighbourhoods as multifunctional units. Within a residential area, there should be provisions for workplaces, educational institutions, cultural facilities, and services. This will not only enhance resilience but also strengthen social integration. • To develop alternative routes using different types of transport — from buses and trams to bike lanes and pedestrian paths — so that the neighbourhood is not cut off in case of an emergency. • To strengthen green belts. They serve as ecological barriers, improve the microclimate, and increase the overall comfort of living in neighbourhoods. • To ensure strict compliance with sanitary distance regulations between residential areas and industrial enterprises or high-risk facilities. This will minimise pollution risks and enhance the safety of the population. • To develop neighbourhood councils with budgets and real powers to manage infrastructure, respond to challenges promptly, and support local initiatives. This strengthens local autonomy and increases the adaptability of territories.	• To include backup elements in transportation and services, plan alternative routes and local supply points; incorporate redundant infrastructure and spaces into the design, which are essential in crisis conditions. • To support the self-organisation of residents, implement more mechanisms and platforms for civic engagement at the neighbourhood level. In many Ukrainian cities, it was through the self-organisation of residents — volunteer initiatives and horizontal support networks — that resilience was maintained in difficult conditions. • To delegate more authority to neighbourhood structures — strengthen local self-government at the level of neighbourhoods, housing companies, cooperatives, and buildings, and create reserve budgets at each level for quick response in emergencies

Table 12. Recommendations for further regeneration of neighbourhoods (Spatial layer "City location")

Spatial layer "Morphology"

Large-scale housing estates in East Germany, built in the 1980s as part of mass industrial construction, initially featured a high degree of standardisation. The spatial structure of these neighbourhoods was based on a typical series of residential buildings, high building density, and minimal consideration of local conditions. The morphology was defined by the uniformity of architectural solutions and a limited set of social objects, also designed using standardised projects. Over time, as the housing stock aged and social needs changed, the morphology of these areas began to evolve. In the 1990s, processes of renovation, infill construction, and, in some cases, demolition of buildings began. This response aimed to address the deteriorating condition of housing, a decreasing population, and the desire to improve the quality of the urban environment. As part of the modernisation efforts, the organisation of courtyard spaces was actively rethought. Courtyards, previously perceived as transit zones, were landscaped and took on new functions, ranging from resting areas to playgrounds and public spaces. Service and leisure facilities appeared on the ground floors, which enhanced the functional diversity of the environment. In some cases, building density decreased due to the demolition of individual residential blocks. The freed-up areas were transformed into green spaces, public zones, or were redeveloped with new, more diverse housing types. Thus, despite the initial standardisation, the morphology of these neighbourhoods evolved toward greater adaptability, diversity, and resilience to social and spatial changes.

The comparative analysis of the resilience of the spatial layer "morphology" in large-scale housing estates of East Germany, built in the 1980s, demonstrates varying degrees of resilience to contemporary challenges depending on the level of modernisation, building density, and morphological diversity. The highest levels of resilience are recorded in the Eastern neighbourhood in Hellersdorf Promenade in Berlin. After 1990, a large-scale centralised modernisation program was implemented, covering over 60% of the area, which helped strengthen the integrity of the urban fabric. High density, a mix of buildings of varying heights, and ar-

chitectural diversity provided the area with significant robustness. Despite certain vulnerabilities to infrastructure and climate risks, the area demonstrated a high degree of spatial resilience and potential for future adaptation.

The next in line in terms of morphological resilience is the Western neighbourhood in Neu-Paunsdorf in Leipzig. Here, the modernisation was also centralised. The absence of building demolitions helped maintain morphological integrity. However, the neighbourhood suffers from monotonous residential development and insufficient adaptability: limited possibilities for repurposing and weak functional diversity reduce its potential for sustainable transformation. Despite basic resilience to physical threats, the area needs strategic measures to develop morphological redundancy, strengthen connectivity, and introduce new functions to enhance resilience.

Less resilient are the neighbourhoods of the North-Eastern neighbourhood in Neu-Gorbitz in Dresden and Residential Complex No. 1/4 in Silberhöhe in Halle. In the first case, resilience is limited by the low level of modernisation and the demolition of a significant portion of residential buildings, which led to a sparse structure and loss of continuity in the urban fabric. The neighbourhood demonstrates some physical resilience but is limited in its capacity for adaptation and functional renewal. In Halle-Silberhöhe, the situation is even more critical. Without large-scale, comprehensive measures aimed at increasing adaptability, functional diversity, and integration into the urban system, the resilience of the neighbourhood will remain below average.

Drawing on the German experience, the following measures can be applied to the spatial layer of "morphology" when rebuilding and regenerating Ukrainian neighbourhoods. At the same time, despite the challenges Ukrainian neighbourhoods face, certain aspects of their building morphology may offer valuable insights for enhancing resilience in German neighbourhoods.

Recommendations for Post-War Regeneration of Ukrainian neighbourhoods	Recommendations for German neighbourhoods
• To reconsider the functions of the ground floors of existing buildings and, where development potential exists, adapt them for public use. • To limit the height of new buildings integrated into existing residential areas, and, where possible, avoid reconstructing destroyed buildings to their original scale. Instead of replacing lost housing with identical structures, opt for buildings of different typologies. The experience of German neighbourhoods has shown that buildings with 3–6 floors are not only more resilient to crises but also provide a safer and more comfortable living environment. • To design new public buildings with the possibility of transformation and multifunctional use in mind. Schools, sports halls, cultural centres, and other facilities should have structural flexibility that allows them to be used in emergencies, from shelters to humanitarian aid centres. • To implement energy-efficient technologies such as insulation, passive heating, solar panels, and energy-efficient windows and doors. This should become a mandatory component of residential district renovation in Ukraine. • To ensure the inclusivity of all public and residential buildings by equipping them with ramps, elevators with voice guidance, navigation systems for the visually impaired, wider pedestrian routes, and ergonomic staircases. • To form a more diverse morphology even within standard construction frameworks. This could move away from excessive regularity and predictability, promoting a human scale and a more vibrant environment.	• To design new multifunctional buildings and spaces. Schools, sports halls, cultural centres, and other facilities should be designed or adapted in such a way that they can perform alternative functions in emergencies, from shelters to humanitarian aid centres. This will increase the resilience of neighbourhoods during war, crises, or natural disasters. • To adapt existing houses to potential crisis conditions, for example, by reserving part of the basement areas for conversion into shelters against military threats, with the necessary critical infrastructure and equipment in place. New buildings being constructed in the area should incorporate such solutions in their designs. • To design areas where temporary, low-cost structures can be quickly erected to establish field hospitals, overnight accommodations, shelters, market areas, and offices for humanitarian services. • To use existing buildings, partially adapting them to current needs without expensive reconstructions or the need for new buildings. The Ukrainian approach of „don't demolish — but improve" helps preserve housing and resources.

Table 13. Recommendations for further regeneration of neighbourhoods (Spatial layer "Morphology")

Spatial layer "Mobility"

The morphological structure embedded in the transportation organization of the neighbourhoods was shaped at the intersection of modernist principles and the growing automobile dependence: a linear street and road network providing a clear hierarchy of movement; wide thoroughfares; designated zones for cars; a well-developed public transport network; and pedestrian routes separated from vehicle flows. These principles allowed for functionality and safety in the early stages of operation. However, over time and with changing urban environment requirements, the neighbourhoods have undergone adaptive transformations. In the context of climate change, demographic shifts, and the drive to reduce carbon emissions, there has been a shift towards more sustainable mobility: bicycle routes have expanded, the dominance of private cars has decreased, and integration with regional transport networks has strengthened. Measures have been implemented to improve accessibility for people with disabilities and elderly residents, and intra-quarter spaces have increasingly been transformed into pedestrian zones with improved navigation and green infrastructure.

The analysis of mobility resilience in the studied neighbourhoods shows that the most resilient in terms of mobility are the Eastern neighbourhood in Hellersdorf Promenade in Berlin and the Western neighbourhood in Neu-Paunsdorf in Leipzig. They demonstrate a high degree of integration of different types of transport, inclusiveness of pedestrian environments, digitalised management systems, and access for emergency services. However, both neighbourhoods are vulnerable due to insufficient decentralisation and limited redundancy, which reduces their ability to adapt to large-scale crises, including power outages and the destruction of centralised infrastructure.

The North-Eastern neighbourhood in Neu-Gorbitz in Dresden, despite the absence of a metro system and its distance from railway stations, demonstrates internal connectivity, an effective tram system, and inclusive infrastructure. Its resilience in everyday conditions is provided by basic functionality, but, as with other neighbourhoods, limited flexibility and centralised management reduce its resilience to extreme threats.

The least resilient is Residential Complex No. 1/4 in Silberhöhe, where there is insufficient development of an inclusive environment, limited protection of transport infrastructure, and a relatively low level of flexibility. Despite the presence of various types of transport, the area remains vulnerable to systemic failures and requires significant transformation towards decentralisation, increased physical protection, and the implementation of backup mobility scenarios.

Recommendations for Post-War Regeneration of Ukrainian neighbourhoods	Recommendations for German neighbourhoods
• To create transport corridors with priority for public transport and minimise transfer times, especially in high-density areas. • To create a flexible route network structure that allows for traffic reconfiguration in response to changing conditions (repairs, emergencies). • To redesign intra-block roadways, considering extra width, removal of obstacles, and parking control. • To create universal barrier-free spaces with low curbs, wide sidewalks, tactile indicators, and accessible platform entrances. Design all routes and stops with the needs of people with disabilities. • To illuminate movement routes, especially near schools, hospitals, shopping malls, and transport stations. • To develop comprehensive cycling paths • To integrate mobility management technologies into the spatial structure: information panels, digital displays, and QR codes at stops, etc.	• To implement mechanisms for emergency scenario planning and adaptive logistics that allow for quick responses to disaster, whether natural, technological, or military • To integrate people protection into the transportation infrastructure, design metro stations with enhanced resilience to external threats and expanded functionality, create bus stops combined with blast-resistant shelters, and provide the possibility of sheltering inside for some time • To develop mechanisms for the temporary legalisation or rapid inclusion of small carriers in emergencies. • To ensure activation of backup, "analogue" transportation solutions that can be quickly deployed in the event of cyberattacks, power outages, or extreme weather conditions. • To reconsider the potential of automobile, bicycle, and pedestrian mobility as survival tools in extreme conditions • To develop logistics considering a complete system collapse: create evacuation routes, backup terminals, redundant operators, and resilient connections between districts. This is a new level of planning based not on growth projections but on destruction scenarios.

Table 14. Recommendations for further regeneration of neighbourhoods (Spatial layer "Mobility")

Mobility in postmodern residential neighbourhoods from the 1980s in Germany maintains basic resilience under stable conditions, but to enhance resilience in the face of growing global risks, measures need to be taken to improve adaptability, decentralisation, and autonomy of transport systems. Ukrainian urban planners could learn a lot from the approaches already implemented in German large-scale housing estates from the 1980s, especially when regenerating Soviet-era large-scale housing estates.

Spatial layer "Function"

The large-scale housing estates in Germany from the 1980s were originally designed with a minimal set of everyday service facilities. District centres were limited in size and typically included administrative, cultural, and recreational elements placed along main roads, pedestrian routes, or scattered randomly within residential blocks. During the late socialist period and the transition to a market economy, these areas experienced the first wave of functional decline: many institutions were closed, repurposed, or privatised, significantly reducing access to essential services. In the 1990s and 2000s, the situation worsened as population decline, demolition of public buildings, and the degradation of socio-cultural infrastructure led to a profound erosion of the urban fabric. A third phase began after 2015, when a large influx of migrants and refugees placed renewed demographic pressure on these districts, resulting in an acute shortage of schools, kindergartens, and service facilities.

Among the studied neighbourhoods, the highest level of functional resilience is found in the Eastern neighbourhood in Hellersdorf Promenade and the North-Eastern neighbourhood in Neu-Gorbitz. These areas offer a relatively balanced mix of residential, commercial, medical, and socio-cultural infrastructure, are well integrated into city networks, and have potential for adaptation, provided modernisation is strategically implemented. However, both remain vulnerable due to insufficient diversification, limited reserve capacity, and a lack of protective infrastructure.

The Western neighbourhood in Neu-Paunsdorf shows only moderate resilience. Its basic functionality depends heavily on external connections, while local flexibility and autonomy remain weak, and strategic reserves are lacking. The most vulnerable area is Residential Complex No. 1/4 in Silberhöhe, where fragmented infrastructure, social instability, and the absence of adaptive resources create high risks during systemic disruptions.

A shared issue across all neighbourhoods is the legacy of 1980s planning: a minimalist functional framework, further

Recommendations for Post-War Regeneration of Ukrainian neighbourhoods	Recommendations for German neighbourhoods
• To adapt Ukrainian neighbourhoods to the „15-minute city" model, ensuring that residents have access to all essential services required in crises without needing to leave the neighbourhood. • To critically assess the redundancy of key functions and initiate the creation of alternative, non-commercial, socially oriented institutions, primarily medical, grocery, and service-related. • To use the same buildings and spaces in a flexible, time-shared format — for example, a school during the day and adult education courses in the evening. This approach increases functional capacity without the need to construct new buildings. • To implement everyday safety infrastructure — including lighting, visibility, and police accessibility — to enhance security at the local level.	• To support small local businesses in neighbourhoods to increase the density of essential services (such as shops, pharmacies, and household services). The presence of numerous small retail outlets and service providers in Ukrainian neighbourhoods helped maintain supply and basic services even when large networks failed. German neighbourhoods should consider implementing tools to support local microeconomies as a strategic response to systemic crises. • To develop mechanisms and plans for the rapid deployment of mobile medical units, the conversion of basements and underground parking lots into shelters, and the creation of temporary humanitarian aid distribution points. • To acknowledge the importance of backup forms of local economy and self-sufficiency during times of disruption, including access to cash, water, food, medicine, and clothing. • To use smart survival technologies: implement automated management of services, from self-checkout systems in supermarkets to mobile medical and social support units. Minimise the risk to staff at critical facilities and actively introduce independent charging stations.

Table 15. Recommendations for further regeneration of neighbourhoods (Spatial layer "Function")

weakened by institutional and demographic decline in the following decades, has resulted in poor spatial and service connectivity. Recent regeneration efforts address some of these problems but fall short of resolving core issues such as the lack of emergency shelters, autonomous energy systems, and resilient mobility options.

Improving functional resilience in these areas requires the development of multifunctional spaces, strengthening of local self-sufficiency, adaptive transport systems, and the integration of crisis-response technologies. Only through a comprehensive transformation of both physical infrastructure and social systems can a sustainable balance be achieved between day-to-day functionality and crisis preparedness.

Based on the analysis of German and Ukrainian neighbourhoods, several strategic directions can be identified for adapting the "function" layer in Ukraine's large-scale housing estates, while Ukrainian practices may, in turn, offer valuable lessons to enhance resilience and flexibility in German districts.

Spatial layer "Greenery/Public spaces"

In the planning of large-scale housing estates in Germany in the 1980s, significant courtyard and inter-courtyard spaces were envisaged, sometimes with a semi-enclosed structure, creating a private atmosphere and favourable conditions for everyday communication between residents of different ages and social groups. These spaces were complemented by linear and clustered green plantings, squares, and small parks, which were integrated into the citywide green system. The green infrastructure was designed as multi-level: lawns, shrubs, trees — forming biological diversity and contributing to the mitigation of climatic conditions in the urban environment. Such green zones perform not only an aesthetic but also an important climatic, ecological, and social function, especially under conditions of growing urbanisation.

Since the late 1990s, under economic pressure and limited municipal budgets, the implementation of the originally laid comprehensive solutions for improvement and maintenance of green areas in several neighbourhoods slowed down or was postponed. In some cases, this led to partially abandoned use of open territories, a decrease in environmental quality, and their fragmentation. At the same time, processes of physical and social ageing of the residential development were taking place, which aggravated the need to rethink the role of green and public spaces in the life of neighbourhoods.

Since the beginning of the 2000s, in several German cities, renovation and rehabilitation programs for large-scale housing estates began, such as "Soziale Stadt" and IBA (Internationale Bauausstellung) initiatives, including elements of tactical urbanism, participation of residents in design, and integration of ecosystem approaches. Temporary green installations, urban gardens, and projects like "Living Labs" (JCOM, 2023) appeared, which became spaces for social interaction, environmental education, and implementation of sustainable daily practices. Residents themselves — including elderly people, migrants, and youth — began to take increasingly active part in these initiatives, which enhanced inclusivity and strengthened the social fabric of neighbourhoods.

Nevertheless, researchers of public spaces in large-scale housing estates in cities of Eastern Germany note that several challenges remain relevant (Haase et al., 2019). Densification of development, reconstruction of the old housing stock, and pressure from commercial interests have, in some cases, led to a reduction in publicly accessible green areas, as well as to their uniformity and functional poverty. In addition, in some neighbourhoods, a lack of strategic approach is observed in differentiating the functions of public spaces — from zones of silence and solitude to places for active recreation, meetings, and joint activities.

The comparative analysis of the spatial layer "greenery and public spaces" shows that the most resilient in ecological and social aspects are the neighbourhoods of Eastern neighbourhood in Hellersdorf Promenade, Western neighbourhood in Neu-Paunsdorf, and North-Eastern neighbourhood in Neu-Gorbitz, where continuous green frameworks have been formed, there is a high degree of integration with the urban green network, and desirable indicators for public green areas are met. These areas demonstrate quality maintenance of green zones, structural integrity, ownership diversity, and accessibility for all population categories. However, each of them has certain limitations: from insufficient functional density and weak redundancy (Eastern neighbourhood in Hellersdorf Promenade) to limited adaptability to emergencies (Western neighbourhood in Neu-Paunsdorf) and weak connection to urban social processes (North-Eastern neighbourhood in Neu-Gorbitz). Residential Complex No. 1/4 in Silberhöhe, despite its significant potential — including the largest courtyard area and high degree of greening — demonstrates low flexibility, limited inclusivity, and poor management sustainability, reflected in the presence of abandoned areas, "places of fear," and weak resident involvement. In this area, the green infrastructure has lost part of its social

and functional role, requiring a rethinking of its usage and support mechanisms.

Approaches to enhancing green public spaces in large German neighbourhoods can inform the regeneration of Ukrainian housing estates, while specific adaptive practices from Ukraine, despite resilience challenges, offer valuable insights for German planners:

Spatial layer "Climate adaptation"

The climate resilience of the original spatial structure of the neighbourhoods was low. A high percentage of impermeable surfaces (asphalt, concrete), predominance of vacant plots between buildings without a clear functional program, and insufficient greenery characterised the area. Large flat facades of high-rise panel buildings with high thermal mass created an urban heat island effect during

Recommendations for Post-War Regeneration of Ukrainian neighbourhoods	Recommendations for German neighbourhoods
• To reassess the connectivity and redesign existing green spaces in neighbourhoods. German neighbourhoods demonstrate that a connected framework of alleys, parks, courtyards, and bike routes provides convenient access, improves ecological sustainability, and creates a cohesive living environment. • To introduce greater functional diversity in green zones — from courtyard gardens and playgrounds to natural areas and quiet zones — to consider the interests of various population groups. • To improve the regular maintenance of green plants and public spaces. • To ensure barrier-free and inclusive public green spaces and accessibility for people with limited mobility. • To implement the practice of utilising vacant spaces for temporary functions and public initiatives (tactical urbanism). For example, use green areas as spaces for introducing green innovations — ecological schools, community gardens, and pilot management projects. • To reduce the number of closed-off areas, transforming them into public or semi-public spaces, and creating equal access to nature for all citizen groups. • To develop local self-governance and transfer the management of green zones to homeowners' associations (HOAs), initiative groups, and cooperatives, stimulating residents' participation and fostering a sense of responsibility. • To create transformable, modular spaces that can be reconfigured for different needs depending on the season or weather conditions (e.g., a summer stage turned into an ice rink in winter), ensuring more efficient use of space.	• To encourage more involvement and initiatives from residents to take care of green spaces themselves. Ukrainian neighbourhoods are implementing urban farming practices, where residents can grow vegetables and herbs in front-yard flower beds. • To consider how green infrastructure will correlate with civil defence infrastructure, ensuring quick access to shelters from public spaces in case of crisis conditions, such as military threats. German cities could integrate shelter elements, modular structures, or spaces suitable for emergency use. • To develop mechanisms for the swift transformation of courtyards and green spaces for emergency tasks, such as logistics, volunteer support, or temporary accommodation, should be developed.

Table 16. Recommendations for further regeneration of neighbourhoods (Spatial layer "Greenery/Public spaces")

summer months, leading to local overheating of the environment and reduced microclimatic comfort. With the collapse of the GDR and a decline in population density, many large housing estates faced a new spatial situation: an increase in vacant plots due to building demolitions and partial degradation of inter-block spaces. In the early stages of redevelopment (1990s and early 2000s), climate adaptation was hardly considered: greening was sporadic, and new spaces often lacked shade and water retention capacity. Gradually, as part of the restructuring process, elements of green infrastructure aimed at increasing climate resilience were introduced. Efforts were made to integrate green areas into the city's water-green system, use biodiverse plantings, and restore or create drainage and water retention zones. Against the backdrop of changing climate conditions (rising temperatures, more frequent droughts and heavy rains), neighbourhoods began implementing targeted adaptive solutions: planting shade trees, installing highly permeable surfaces, introducing green roofs and facades, and creating rain gardens and retention basins. Nevertheless, contradictions often remained between the need for densification and the necessity to expand green areas for effective climate regulation.

The neighbourhoods show both common features in their approaches to climate adaptation and distinct individual characteristics. The neighbourhoods with the highest level of climate resilience are the Eastern neighbourhood in Hellersdorf Promenade and the Western neighbourhood in Neu-Paunsdorf. These neighbourhoods have implemented projects aimed at spatial transformation considering climate challenges: greening, increasing the albedo of surfaces, partial integration of water retention elements, and the use of digital monitoring systems, with residents involved in maintaining the green framework. The spatial and institutional conditions allow these neighbourhoods to develop a comprehensive adaptation strategy. The North-Eastern neighbourhood in Neu-Gorbitz demonstrates moderate climate resilience. Despite local overheating zones and limited redundancy in green infrastructure, the area is characterised by a diversity of solutions, high permeability, and active use of tactical urbanism. However, chronic climate effects and insufficient variability in strategies limit its climate flexibility. Residential Complex No. 1/4 in Silberhöhe remains the most vulnerable neighbourhood. To enhance the overall resilience of the studied neighbourhoods, the following areas need strengthening: the development of water-retaining green infrastructure solutions (green roofs, walls, rain gardens), the introduction of automatic irrigation systems, spatial integration of water elements, expansion of tactical urbanism practices, and ensuring social inclusivity in planning. Only a comprehensive approach that combines natural, spatial, and social aspects will ensure sustainable adaptation of these neighbourhoods to changing climate conditions in the long term.

Based on the German experience, the following possible measures can be proposed for Ukrainian neighbourhoods:

- To implement modern stormwater systems with the ability to accumulate, filter, and reuse rainwater. German experience shows that such solutions are necessary in conditions of increased rainfall and help mitigate the consequences of urban drainage infrastructure overload.
- To move away from monoculture landscaping and use a variety of plants — trees, shrubs, perennials, grasses — as well as green roofs and walls. This significantly enhances the climate resilience of the neighbourhood, strengthens biodiversity, and improves air quality.
- To develop interconnected green corridors and reserve areas that can compensate for the loss of individual green infrastructure areas due to construction or natural disasters.
- To use materials with high reflectivity (high albedo), light-colored facades, and resilient plants capable of withstanding droughts and heavy rainfall. These measures will reduce overheating and increase the longevity of the urban environment.
- To provide special solutions for the elderly, children, and people with disabilities — shade canopies, drinking fountains, and protected rest areas. This not only increases comfort but also protects the most vulnerable residents from climate risks.
- To implement "living laboratories" in neighbourhoods — this will allow testing experimental and innovative solutions in real conditions.
- To use permeable pavements, grass pavers, and mixed types of paving that help improve water balance while also reducing surface temperatures during hot weather.
- Climate adaptation should become an integral part of master plans and urban development strategies, not just a temporary measure.

Spatial layer "Critical Infrastructure"

Initially, the development of these neighbourhoods involved the large-scale construction of centralised urban infrastructure. This included heat power plants, water treatment stations, and networks for electricity supply, sewage, stormwater drainage, and gas supply. In the early stages of operation, the infrastructure condition was satisfactory, supported by planned repairs and ongoing monitoring.

However, over time, the engineering systems began to deteriorate, necessitating a shift from isolated repairs to systematic monitoring and comprehensive modernisation. Maintaining infrastructure functionality has since relied on regular inspections, partial upgrades, and repairs, though the need for deeper transformation remains.

In all neighbourhoods, electricity supply is centralised and delivered via transformer substations, each serving multiple residential buildings. Recently, solar collectors for water heating have been introduced, but their installation scale remains insufficient for achieving a highly resilient environment. Internet connectivity is provided exclusively by commercial providers through cable networks, with no backup channels, including satellite technologies, creating vulnerabilities during emergency outages or targeted cyberattacks. Radio communication is maintained by state broadcasting, but resident engagement is extremely low.

Centralised water supply and sewage systems operate reliably; however, the absence of backup reservoirs, accumulators, and local treatment facilities poses potential risks during crisis events. Gas is not used in households, reducing the risk of leaks and explosions, but this also means there are no alternative cooking options during power outages, such as specially equipped open-air cooking areas. Heating in all neighbourhoods is also centralised, without local or alternative sources. Considering the wear on heating pipelines and the need for regular repairs, this dependence could become critical if cen-

Recommendations for Post-War Regeneration of Ukrainian neighbourhoods	Recommendations for German neighbourhoods
• To develop distributed energy sources. Installing solar panels on the rooftops of residential buildings and creating local microgrids will enable neighbourhoods to generate their electricity during outages and reduce dependence on centralised supply systems, at least temporarily. • To establish local water reserves and small-scale purification systems. In conditions of unstable water supply, each neighbourhood needs to have access to backup sources, ranging from underground wells to storage tanks equipped with filtration stations. • To reduce dependence on household gas, and develop outdoor cooking areas is advisable. • To integrate elements of grey infrastructure for rainwater collection. This will reduce pressure on sewer systems while also creating an additional water resource. • To implement digital monitoring and management. Ukraine should adopt IoT sensors for network wear assessment, remote diagnostic systems, and predictive analytics. These will help detect and resolve faults early, improving infrastructure reliability. • To strengthen architectural and technical integration of infrastructure systems within neighbourhoods. In Ukrainian cities, fragmentation is often observed — water, heat, electricity, and communication are managed by different entities with little coordination. The German example shows that a unified neighbourhood-level management system enables rapid response to challenges, resource optimisation, and cohesive urban environments. • To develop crisis thinking and scenario-based planning at the neighbourhood level: creating evacuation plans, maintaining emergency reserves, and developing protocols for interaction between services and residents.	• To implement decentralised basic service systems for critical facilities. The Ukrainian experience highlights the necessity of autonomous supply nodes — for heat, water, energy, and communication — at every school, hospital, and administrative building. Germany could adopt this model to strengthen the resilience of its social infrastructure during outages or crises. • To integrate low-tech solutions into urban infrastructure. Ukraine has demonstrated how simple, autonomous technologies — hand pumps, mobile water filters, wood-burning stoves — can ensure basic survival when centralised systems fail. Germany may consider incorporating such solutions as backup mechanisms, particularly in remote or vulnerable areas. • To equip neighbourhoods with local command centres, storage facilities, backup energy sources, and water supplies, enabling them to function independently from central networks. • To construct redundant engineering infrastructure. Ukraine is learning to build redundancy into critical systems: alternative communication routes, local heating sources, and backup water and energy access points. German neighbourhoods could pursue similar redundancy to improve emergency preparedness. • To use the experience of horizontal self-organisation in times of crisis. Ukrainians actively establish volunteer centres, chat groups, and neighbourhood initiatives that enable rapid response without centralised management. Germany can draw on this approach to enhance civic autonomy when institutional systems are overloaded or unavailable.

Table 17. Recommendations for further regeneration of neighbourhoods (Spatial layer "Critical Infrastructure")

tralised systems fail. Currently, no backup solutions to ensure autonomy during crises are in place.

The quality of the "grey" infrastructure, including the stormwater drainage system, is generally satisfactory under normal weather conditions. However, during heavy rainfall, instances of overload occur, indicating a need for modernisation to accommodate the increasing frequency of extreme climate events. Emergency alert systems are operational but are rarely tested beyond scheduled exercises, reducing their reliability during real threats.

Ukrainian neighbourhoods can draw on German experience to improve the resilience of the "critical infrastructure" spatial layer, especially given the acute challenges posed by Russia's targeted attacks during the war, which have prompted a fundamental reassessment of this layer's resilience.

Spatial Layer "Identity"

The initial spatial organisation of German large-scale housing estates aimed to create coherent spatial compositions with semi-enclosed courtyards framed by green infrastructure. Facades featured a restrained colour palette, monumental art, supergraphics, and minimal decorative elements limited to stairwells, entrances, and balconies. Over time, this identity changed significantly. The removal of communist-era symbols and visual propaganda led to a partial loss of the original image, while spontaneous resident markings such as graffiti — sometimes linked to youth subcultures — further altered the visual character.

Subsequently, neighbourhoods began actively redefining their spatial identity through facade renovations, apartment modifications, and public space upgrades — a pro-

Recommendations for Post-War Regeneration of Ukrainian neighbourhoods	Recommendations for German neighbourhoods
• To develop and implement long-term programs for the planned renewal of neighbourhoods, involving residents and coordinating with municipal authorities. • To foster managed and conceptually grounded environmental diversity by introducing new functions (e.g., gardens, community centres, playgrounds) while avoiding spontaneous architectural fragmentation. • To create reserve public spaces (e.g., temporary parks on vacant plots) to increase the environment's resilience to loss and change. • To ensure the architectural stability of neighbourhoods through regular—even minimal—investment in building renovation and maintenance. • To integrate safety aspects into architectural and planning decisions by improving lighting, ensuring visual oversight, and equipping high-quality public zones. • To develop adaptive modernisation strategies for buildings and public spaces in collaboration with local communities, taking demographic and social changes into account. • To design flexible-use spaces that can adapt to new functions without the need for major reconstruction. • To ensure physical and social inclusivity of the environment by developing infrastructure accessible to all age and social groups, including people with limited mobility. • To encourage local innovation through grant support, architectural and cultural initiatives, festivals, educational, and urban development projects. • To create a balanced decentralisation system, where bottom-up initiatives are supported within a unified strategic framework for neighbourhood development, ensuring environmental cohesion.	• To encourage individual participation in shaping the urban environment. The Ukrainian experience shows that creative reinterpretation of space (e.g., painted Soviet-era playgrounds, mosaics, individual landscaping) can revitalise the environment and strengthen residents' emotional attachment. • To support bottom-up environmental adaptation. German neighbourhoods can take inspiration from how local initiatives in Ukraine — from garage cooperatives to informal markets — act as forms of adaptation to changing conditions and signal which transformations need to be formalised in safe and resilient ways. • To integrate everyday experience into resilience strategies. In Ukrainian neighbourhoods, identity is shaped through the lived experience of instability — this experience can inform the development of resilience strategies in Germany, particularly in times of crisis. • To avoid limiting modernisation to technical measures only. The Ukrainian experience of de-occupation demonstrates the importance of symbolic, sociocultural, and visual components in shaping local identity. • To build resilience based on social inertia. Ukrainian neighbourhoods have shown that even under stagnation and in the absence of centralised policy, resilience can be maintained through recurring practices and local familiarity — a resource that can be reinterpreted in the German context.

Table 18. Recommendations for further regeneration of neighbourhoods (Spatial layer "Identity")

cess that continues today with growing involvement from residents.

The development of resilience within the spatial identity layer shows positive momentum but still requires integrated efforts to strengthen social cohesion, enhance environmental quality, and preserve unique character. Particular attention must be paid to social vulnerability, stigmatisation, and economic risk, especially in disadvantaged areas. A renewed identity should reflect not only architectural transformation but also the real needs of communities, involving all social groups in shaping the future of their neighbourhoods. Long-term resilience will depend on restoring cultural heritage, improving public spaces, and reinforcing social ties, while maintaining architectural and ecological features that support the cultural distinctiveness of each area in the face of social and economic change.

In the context of global crises, cross-border exchange of knowledge and practices becomes especially important, where the Ukrainian experience of resilience, shaped under extreme conditions, can enrich even the most advanced models. Survival architecture based on self-organisation, trust, and flexibility complements technocratic approaches, and urban recovery requires not only engineering solutions but also humanitarian rethinking. As a result, the viability of 21st-century cities will depend on the ability to combine technology and empathy, centralised planning and grassroots initiatives, shaping resilience as a product of collective effort.

8 Spatial development scenarios for neighbourhoods in large-scale housing estates

Based on the analysis of threats, general and spatial resilience characteristics, scenarios for neighbourhoods of large-scale housing estates have been developed to enhance their resilience. The proposed scenarios consider both short-term and long-term goals, varying degrees of threats, and the potential of neighbourhoods. They range from targeted improvements to complete reconstruction, providing flexibility in decision-making. This allows for the adaptation of development to specific conditions and increases the resilience of residential areas.

Scenario 1 is typically chosen due to a lack of resources, the absence of urgent threats, or the desire to preserve historically established urban structures. It is often viewed as a temporary measure in situations where geopolitical, social, and economic risks prevail, making comprehensive reconstruction difficult. The goal of this scenario is to maintain a basic level of resilience and quality of life without intervening in the spatial organization of the neighbourhood (Fig. 29). At the building level, repair work is carried out on the engineering infrastructure, facade updates with new color and plastic solutions are applied, and energy-efficient technologies are introduced. Cosmetic and functional changes to the interior spaces of residential buildings are possible, as well as the greening of roofs and walls, which helps to increase the comfort and resilience of buildings against external impacts. At the level of a group of buildings, the main focus is on improving the quality of the everyday environment. Car and bicycle parking lots are organised, and children's and sports playgrounds, as well as utility zones, are modernised. Maintenance of courtyard greenery and adjacent areas is carried out. Special attention is given to inclusion — sanitary points adapted for people with disabilities, the elderly, and victims are created to foster a fairer and more accessible environment. At the neighbourhood level, measures are taken to improve the conditions of public use. A sufficient number of parking spaces is provided near public buildings, and spaces for joint activities of residents are created, such as community gardens, dog walking areas, and sports zones.

Intra-quarter greenery is actively supported, including by planting trees in overheated areas. Given the relevance of geopolitical and social risks, the organisation of micro-social shelters in the basements of public buildings

and the installation of small above-ground protective structures are foreseen. A cadastral inventory is also conducted to determine property forms and distribute responsibility for the maintenance of the territory. At the levels of the district and the city, no changes are planned within this scenario.

Scenario 2 involves minor spatial changes aimed at locally improving the quality of the urban environment without radically transforming the neighbourhood. This is a moderately active approach, focused on solving specific problems and increasing the comfort of living through targeted interventions in infrastructure and public spaces. At the level of residential buildings, measures are implemented to improve their general condition, such as installing elevators, ramps, and inclusive entryways. First floors may be repurposed into spaces for socio-cultural or commercial needs, and solar collectors may be installed, contributing to energy efficiency and the development of local infrastructure. At the level of a group of residential buildings, measures are taken to improve accessibility, including adaptations for people with limited mobility and ensuring access for special transport. High-quality shelters and resilient points (resilience points) are organised, as well as backup life support systems — water supply, heating, internet, and alert systems, at least for a limited period. Additionally, systems for stormwater drainage and solutions to increase the permeability of the surface area are introduced. At the neighbour-

Fig. 29. Restored part of a building in the Northern Saltivka large-scale housing estate. Facebook

hood level, improvements are made to increase the functional density of the area. A sufficient number of everyday service facilities are ensured — shops, medical institutions, post offices, banks, etc. The role of existing socio-cultural institutions is strengthened, and the possibility of creating new ones or expanding the functions of the existing ones, for example, schools or kindergartens, is considered. Universal access to housing, public buildings, and spaces is provided everywhere. At the residential neighbourhood level, measures are implemented to improve transport connectivity: convenient and inclusive public transport routes are provided, a system of bike lanes is created, and access to everyday infrastructure facilities is ensured both within the neighbourhood and in adjacent areas. At the city level, the neighbourhood is integrated into the overall city transport system: access to intra-city routes and inter-municipal transport hubs (for example, through rapid transfer stations or mobile transport modules) is provided.

Scenario 3 involves the creation of a "green" or "healthy framework" for a large-scale housing estate and focuses on a deep ecological and spatial rethinking of the environment (Fig. 30). This is a more ambitious scenario that includes the introduction of resilient natural solutions, the development of infrastructure for an active and healthy lifestyle, as well as the creation of new green and recreational public spaces (Fig. 28). It requires significant investments and active participation from all levels of governance, but in the long term, it ensures sustainable development and ecological safety for the area. At the level of residential buildings, basic measures to improve their technical condition continue, similar to the previous scenarios. Spatial changes are minimal but are integrated into the overall ecological context of the area. At the level of a group of residential buildings, there is a rethinking of the courtyard spaces. These are redesigned to meet the needs of the residents, functionally zoned, and the responsible parties for the maintenance and operation of the area are designated. New landscaping is introduced, not requiring regular maintenance and playing a key role in forming the "green framework" at the local level. At the neighbourhood level, the main idea of the scenario is implemented — the

creation and strengthening of the green framework. This includes green alleys, areas around educational institutions, squares, and parks, all interconnected into a unified ecosystem and logically linked to the courtyard spaces. Regular maintenance of green zones is ensured, and their usage forms — private, semi-public, collective, or municipal — are fixed. The green framework is enriched with socio-cultural functions: public buildings, open spaces, shelters, and is also reserved for the placement of decentralised critical infrastructure, with the possibility of autonomous operation in emergency conditions. At the district level, the green framework is expanded to include pedestrian and bicycle transit routes connecting residential neighbourhoods with green spaces in neighbouring areas. Concepts for water bodies — artificial reservoirs, fountains, tanks, and marshes — are developed. At the city level, the scenario involves integrating the neighbourhood's green structure into the citywide greening strategy. It ensures the connection of green corridors in the neighbourhood with large green areas both within and beyond the city. This creates a cohesive ecological network that supports urban resilience and adaptation to climate change.

Scenario 4 envisions the creation of a new subcenter within a large-scale housing estate and is aimed at enhancing territorial self-sufficiency (Fig. 31). Unlike previous scenarios, this one focuses primarily on the redistribution of functions within the neighbourhood, the creation of new spaces and points of attraction. This requires a revision of urban zoning, the involvement of private investors, and the development of transport, social, and engineering infrastructure. The scenario calls for complex coordination, investment, and a rethinking of the neighbourhood's role within the city as a whole, but it has the potential to significantly strengthen social resilience and integrate the area into a multi-level system of urban safety and life support. At the level of residential buildings, basic improve-

Fig. 30. Development scenario of neighbourhoods No. 9/10 in Vygurivshchyna-Troieshchyna in Kyiv. DAAD, 2023-2024

Fig. 31. Development Scenario for neighbourhoods No. 9/10 in the Vygurivshchyna-Troieshchyna. DAAD, 2023-2024

ment measures continue, including elements of the green and healthy framework, but they do not undergo significant spatial changes. At the level of housing clusters, the strategy of improving the residential environment and supporting elements of the green framework is also maintained. Spatial interventions at this level are limited. The main transformations occur at the neighbourhood level, where a balanced functional program is developed, incorporating new cultural, educational, medical, and commercial facilities. Public spaces are redesigned with future uses and transformability in mind, and pedestrian, bicycle, and emergency routes are adapted to new conditions. The use of underground space plays a significant role – it is planned for both everyday activities and emergencies, including the placement of critical infrastructure, shelters, and communication systems capable of autonomous operation. The green framework is preserved but integrated into the new spatial organisation with consideration for functional density. At the district level, the concept of a subcenter or a system of subcenters is developed, assigning key service, administrative, and logistics functions to the territory. This may involve creating new hubs of attraction, including facilities for collective use, temporary accommodation, life-support warehouses, and underground evacuation routes connecting different parts of the residential area. At the city level, the scenario involves integrating the new neighbourhood subcenter into the citywide system, with special attention given to transport connectivity and access to critical facilities. The construction of underground transport hubs is considered, designed to serve dual purposes: functioning as transport stations in peacetime and as bunker shelters during crises, equipped with supplies, medical, and social infrastructure.

Scenario 5.1 involves the partial dismantling of buildings to enable targeted modernisation of the urban environment. Unlike more radical approaches, it is limited to the removal of structures that have lost their functional viability or are barely used. The freed-up plots are repurposed for the development of energy-efficient housing and socially significant infrastructure, which allows the district's overall appearance and historically established structure to be preserved. This scenario represents a moderate and carefully considered model of spatial transformation, where the renovation of housing stock and public spaces is carried out with minimal disruption to residents' every-

day lives. Thanks to its selective approach and sensitivity to local context, the scenario promotes the smooth integration of new solutions into the existing urban fabric. At the level of individual residential buildings, the strategy includes the partial demolition of derelict or vacant structures, followed by the construction of new buildings with modern typologies that meet energy efficiency and sustainable development standards. At the same time, options for reconstructing preserved buildings are considered: adjusting building heights, repurposing ground floors for public functions, and organising duplex apartments. A key part of the strategy is the reuse of construction materials, which reduces the environmental footprint and improves the project's economic feasibility. At the level of housing clusters, courtyards and access roads are redesigned based on the new spatial configurations. Changes in movement logic, zoning, and residents' needs are taken into account. The spatial organisation is adapted to the updated morphology of the built environment while maintaining integration into the neighbourhood's green and functional framework. At the neighbourhood level, more profound changes are implemented. Pedestrian, bicycle, and vehicular traffic patterns, evacuation routes, and access to key buildings are restructured. The functional program is updated to reflect new needs: transformable spaces, new public zones, and alternative uses of underground facilities are introduced for both everyday and crisis situations. Critical infrastructure is also redistributed and modernised, including relocation to underground facilities. Special attention is given to managing vacant land parcels, integrating them into the overall regeneration strategy. At the district level, the possibility of incorporating social housing is considered, including determining its proportion and location within the updated residential area. The concept of underground evacuation routes is also emphasised as a component of safety and resilience. The connection between neighbourhood and district levels is reinforced through the development of a subcenter integrated into the overall transportation, social, and environmental system. At the city level, the logic of forming a green framework and subcenters is maintained, enabling the neighbourhood to be embedded into a broader urban strategy for sustainable development. Transportation accessibility is improved, and all transformations are aligned with citywide programs for modernisation, reconstruction, and environmental regulation.

Scenario 5.2 envisions active demolition and represents a radical urban renewal strategy. The scenario requires substantial financial and organisational investment, as well as close coordination among all stakeholders. Temporary inconveniences associated with relocation and disruption of daily life are offset in the long term by the creation of a sustainable, environmentally responsible, and socially focused urban environment. Under this scenario, large-scale demolition of old high-rise residential buildings takes place, except those that hold architectural or social value. On the cleared land, energy-efficient buildings of no more than five stories are constructed, with varied typologies, designed to form a green framework and an inclusive environment that meets the needs of different social groups. A significant portion of the new housing stock is designated as social housing, ensuring accessibility for vulnerable populations. The scenario also considers the radical reconstruction of surviving buildings, reducing height, changing layouts, and repurposing ground floors, including the creation of duplex apartments. This approach enables a diversity of housing solutions and enhances living comfort. A key element is the reuse of construction materials from demolished buildings. Changes affect not only individual buildings but also residential clusters: courtyard spaces are completely reconfigured, and new housing typologies are developed to reflect the neighbourhood's transformed morphology. At the block level, pedestrian and bicycle routes, access roads, and evacuation paths are reimagined — all in line with the green framework, the updated functional program, and cost-efficiency requirements. Public spaces are redefined, incorporating universal and transformable zones tailored to the needs of diverse groups of residents. The use of underground space is also revised, for both daily and emergency purposes, to accommodate decentralised critical infrastructure and autonomous life-support modules. At the district level, a balanced concept is developed for the distribution of various housing types, including social and specialised units, taking into account the future functional development of the area and the need for sustainable connections with adjacent neighbourhoods. The integration of underground evacuation routes into the residential neighbourhood's layout is also considered. At the city level, the neighbourhood is incorporated into the broader system of transport and functional connectivity, as well as into the network of green infrastructure and urban subcenters.

Scenario 5.3 focuses on transforming the existing neighbourhood into a system of compact block development with low-rise but high-density architectural structures. At the level of individual buildings, Scenario 5.3 involves the active demolition of outdated residential and public structures, while preserving only those with significant architectural or cultural value. New energy-efficient buildings, up to five stories high and adapted to modern climate and environmental standards, are constructed in their place. A key element is the reuse of materials from the demol-

ished structures. Residential clusters are formed based on a block development model, characterised by clearly organised perimeter blocks that enclose protected inner courtyards. Each courtyard is designed with future residents' needs in mind and developed with their direct participation, ensuring a stronger alignment with the social and functional fabric of the neighbourhood. These courtyards serve not only as recreational spaces but also as hubs for local community life. At the neighbourhood level, a spatial concept is implemented based on a fine-grained block structure that combines high density, low-rise architecture, and flexible functionality. The layout is supported by an efficient network of pedestrian and bicycle paths, evacuation routes, transport access, and connectivity to public facilities. Public spaces are integrated into the neighbourhood's green framework, taking into account existing green corridors and historically developed natural elements. Special attention is given to inclusivity, with universal and transformable spaces designed to be accessible to all population groups. A comprehensive program is also proposed for the use of underground space in both everyday and emergencies. Underground levels accommodate decentralised elements of critical infrastructure that can operate autonomously during crises. At the district and city levels, morphological and functional elements that contribute most effectively to the resilience of the urban structure are preserved and developed. The scenario ensures that architectural and planning decisions align with citywide programs and subcenter strategies, allowing for seamless integration into the broader urban system.

Scenario 6 represents the most radical and large-scale approach to residential neighbourhood transformation and is applied in situations where the existing built environment has become entirely uninhabitable due to serious technological, environmental, or social threats. This scenario becomes necessary when other measures—ranging from targeted renovation to partial reconstruction — prove ineffective or impossible due to the extent of destruction or degradation of the residential environment. At the building level, a complete architectural renewal is envisaged in line with the overarching concept of the new neighbourhood. New construction is carried out by current standards for energy efficiency, sustainability, digitisation, and environmental responsibility, with an emphasis on the reuse of materials obtained from the demolition of the former structures. The formation of residential clusters is carried out from the ground up, based on the idea of integrated block design. These clusters are conceived as enclosed, functionally rich structures with comfortable internal organisation. A key element of this approach is the participatory design of courtyards and inter-building spaces by future residents, which helps foster a sense of belonging to the new place. At the neighbourhood level, the area is treated as a "blank slate" within the urban planning system. Its development considers all key characteristics—morphological, functional, logistical, climatic, environmental, and safety-related. The spatial concept is based on a new network of connections, efficient function distribution, the formation of a green framework, and the integration of public spaces. Special attention is paid to the universality and adaptability of the environment, inclusivity of all components, and the creation of flexible infrastructure, including underground systems for both everyday use and emergency conditions. At the district level, a programmatic and spatial development scenario is elaborated, integrating the new territory into a broader urban system. The area does not merely replace the old residential block but becomes a component of a new urban framework that considers transport flows, climate resilience, functional distribution, and ecological balance. This provides the opportunity to synchronise the development of the area with the city's overarching strategies for growth and adaptation. At the city-wide level, the new development is positioned as a key element of urban transformation, implementing best practices in terms of morphology, logistics, environmental sustainability, and safety. Particular emphasis is placed on digital design and the adoption of smart city technologies, with data protection, cybersecurity, and technological resilience identified as critical tasks.

The decision to choose a particular transformation scenario for a residential neighbourhood should be based on a comprehensive assessment of the condition of the existing development, as well as the nature and severity of current threats. The scale and pace of implementing changes largely depend on financial capabilities and available resources. A crucial factor for the sustainability and success of any transformation is the active participation of residents at all stages — from identifying problems to shaping the new urban environment. Such involvement helps address the real needs of the community, reduces the risk of social conflicts, and strengthens the sense of belonging, which is essential for the long-term resilience and adaptability of the neighbourhood.

9 Conclusion. Pathways for implementation in Ukrainian municipal practice. What's next?

The concept of urban resilience represents a specific mode of integrated sustainable development activated in response to external or internal threats. Incorporating resilience components into urban development management increases planning flexibility, allows strategies to adapt to changing circumstances, and — most importantly — reduces environmental vulnerability well before a crisis occurs. This approach not only creates a more viable urban structure but also establishes the necessary conditions for implementing sustainable spatial development strategies in post-crisis contexts.

When threats are not sudden, the process of discussing, selecting, and deciding on the best development scenario occurs in a planned manner within integrated development projects. In such cases, the pace of implementation depends on the speed of decision-making, the level of political will, and the amount of budget financing. This process is multi-staged and iterative, involving regular working meetings, consultations with residents, and other stakeholders. This format allows for flexible adaptation of the urban environment to changing conditions, transforming the area step by step.

In the event of critical threats requiring immediate response, the resilience-enhancing mode is activated. Here, unlike the standard planned approach, speed and efficiency are prioritised. Successful response demands prior analytical preparation of the territory, creation of databases, development of scenario response models, and practised decision-making algorithms, which enable faster resource mobilisation and reduce vulnerability to sudden impacts (Fig. 32).

The resilience-enhancing mode can be divided into four phases (Fig. 33). The first phase — immediate response — typically excludes spatial transformations. During this period, the main burden falls on public, economic, and management systems, focusing on organising governance, ensuring safety, and meeting basic life needs. The second phase—adaptation—aims to restore the environment to a condition no worse than before the crisis, while eliminating key threat factors. This stage involves targeted interventions such as repairs, engineering stabilisation, and the construction of temporary or defensive structures.

The third phase — transformation — provides an opportunity for deeper rethinking of space. This stage goes beyond mere restoration to restructuring the environment based on crisis experience, creating new tools to minimise or prevent similar threats in the future. In some cases, a fourth phase — creation — begins, involving the demolition of the original state and formation of a qualitatively new spatial solution capable of withstanding future challenges. Achieving this phase requires sufficient economic, social, and political potential.

Once the situation stabilises and threats subside, the resilience mode gradually transitions into strategic long-term planning. This is reflected in the shift to updated integrated projects that account for the crisis's consequences, adaptive changes, and new governance forms developed in response to emergencies. Such an approach combines situational resilience practices with the sustainable development concept, ensuring not only environmental recovery but also the creation of a more viable, flexible, and transformable city. The practical significance of this approach is especially evident in the examples of Ukraine and East Germany, where research on the resilience of large housing estates serves not only as a theoretical analysis but also as an attempt to implement spatial resilience principles in real conditions. For successful application in Ukraine, it is crucial to adapt the data and recommendations to the unique social, economic, and political realities of post-war recovery.

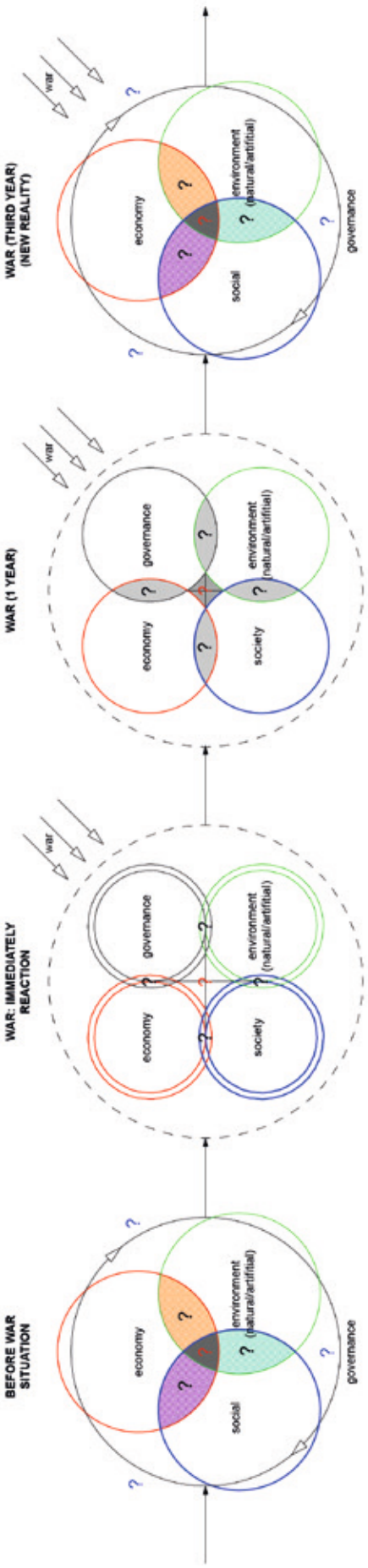

Fig. 32. *Model of transition from the mode of planned integrated urban development to the mode of enhancing resilience. Developed by Nadiia Antonenko*

Integrating resilience into urban development requires concrete actions: developing planning strategies based on resilience principles using modern assessment methods; implementing architectural and infrastructural solutions that support resilience—from environmentally friendly materials to smart systems; actively involving local communities in design and decision-making; and expanding educational programs to raise public awareness about resilience's importance and individual roles in shaping the city's future.

The challenges addressed in this research—climate change, migration, urbanisation, and social inequality—are universal for cities worldwide. The proposed approaches may be useful for other countries facing similar issues and can help create adaptive, resilient, and inclusive urban systems that promote harmonious societal development and peaceful coexistence. The ability to build resilient cities is becoming a key factor in overcoming future crises and ensuring the harmonious development of society overall.

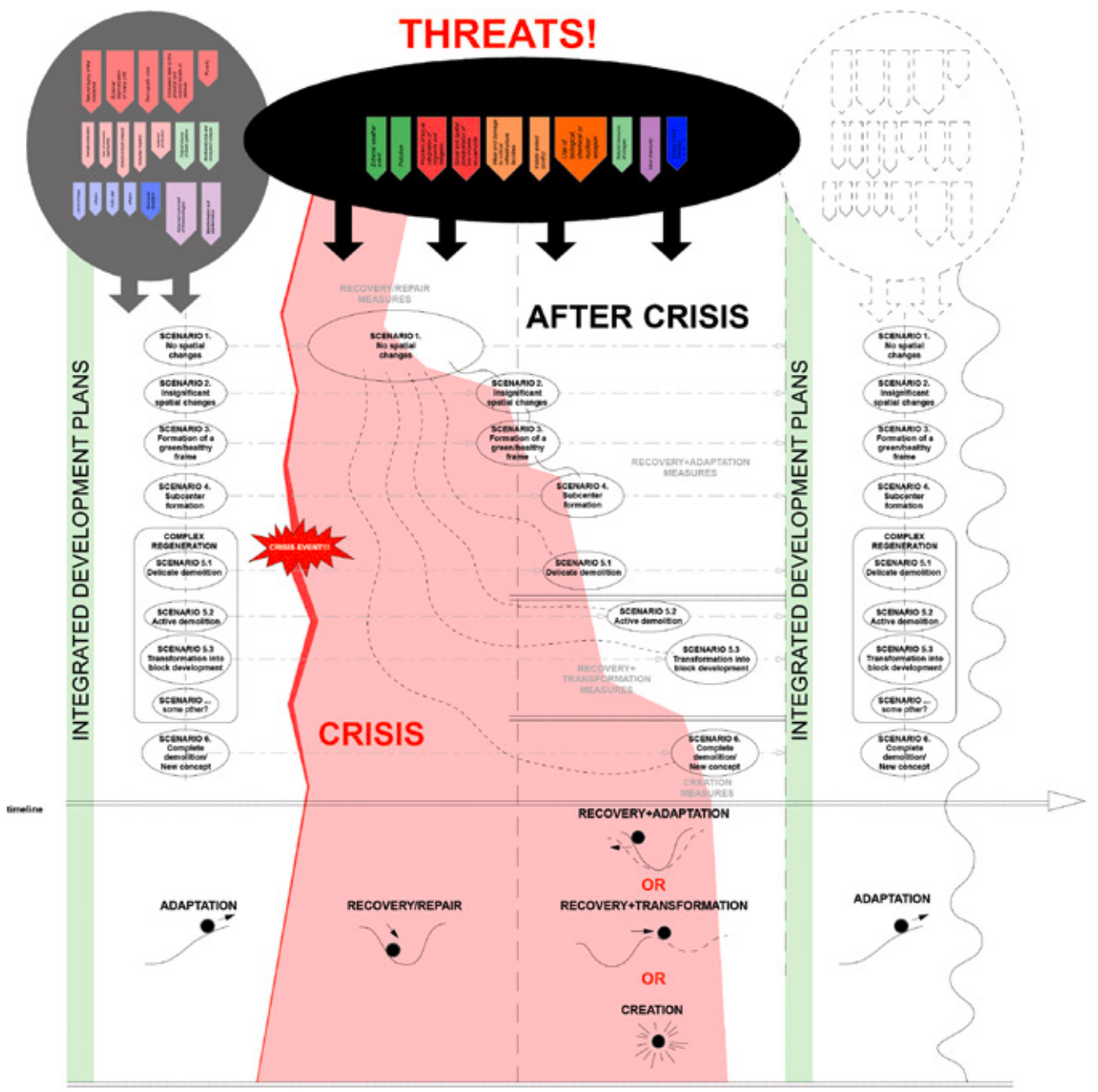

Fig. 33. *Mechanism of implementation of spatial development scenarios for large-scale housing estates within the framework of integrated territorial development. Developed by Nadiia Antonenko*

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LIST OF ILLUSTRATIONS

* The diagrams were developed by students of Ukrainian universities under the supervision of Nadiia Antonenko and Tetiana Rumilets as part of the "Resilient Ukrainian neighbourhoods (LHE)" seminar (Project "Reconstruction Modules Ukraine", funded by the DAAD program "Ukraine Digital").

LIST OF TABLES

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