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Frontiers of Urban Resilience: Multi-Hazard Risks and Nonlinear Recovery Pathways in a Conflict-Exposed City

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Abstract

This research advances understanding of urban resilience amid polycrisis by analysing how continuous military violence interacts with pre-existing urban vulnerabilities. Using Kherson (Ukraine) as a critical case, the research offers a unique lens on urban responses to unprecedented short-term and long-term challenges. It shows how a city that experienced occupation, infrastructural collapse, and depopulation, in the face of constant instability and continuous attacks after liberation, reorganises its socio-spatial systems and shapes its recovery trajectories. Drawing on spatial analysis of destruction, thematic mapping of socio-demographic and logistical changes, and institutional capacity analysis, the study conceptualises recovery as a nonlinear dynamic process that unfolds through absorptive (stabilisation of key functions in partially populated areas), adaptive reorganisation of logistics and service networks, and transformative shifts in the most damaged areas, where conventional models of governance are no longer viable. By situating Kherson in a broader comparative debate, the study offers conclusions relevant to cities in zones of armed conflict, climate disasters, and large-scale social upheaval. The trajectory of urban spatial development in such contexts is characterised by spatial heterogeneity, threshold conditions, and multi-vector processes in which systemic loss, stabilisation, and adaptation occur simultaneously. The case of Kherson demonstrates that continuous military pressure limits traditional reconstruction and urban planning models. The future of cities in a multi-crisis environment depends not only on reconstruction resources but also on rethinking recovery as a new model of socio-spatial development, grounded in absorptive, adaptive, and transformative capacities, differentiated spatial strategies, and context-sensitive governance.

Keywords
bifurcation; polycrisis; reconstruction; recovery; residential district; spatial analysis; sustainable development; urban planning; urban resilience; urbicide

1. Introduction

Modern cities increasingly find themselves in polycrisis, with interlocking economic, social, environmental, and political stressors that co-evolve and amplify one another (Lawrence et al., 2024). This phenomenon has manifested new dimensions of vulnerability (Brosig, 2025) that transcend individual sectors and thereby require systematic analysis (Hoelscher et al., 2022). Economic instability and widening social cleavages, the threat of future pandemics and armed conflicts, alongside uncontrolled migration flows and urban growth, are shaping a new urban reality in which instability has become the norm (Meerow & Newell, 2019). Climate change can exacerbate these crises and further constrain humanity's ability to maintain stability and acceptable standards of living (Rędzińska & Piotrkowska, 2020).

Against this background, "urban resilience" has become a key analytical and practical paradigm—with the comparative capacity of urban systems to absorb, adapt, and recover in response to uncertainty and shock emerging as a core metric of their viability (Soldak et al., 2024).

Despite a significant surge in context-specific studies (Amirzadeh et al., 2022; Büyüközkan et al., 2022), the blanket concept of "urban resilience" remains ambiguous when applied cross-culturally and raises several methodological tensions. For example, who are its stakeholders, what threats does it encompass, what are its temporal horizons, and what are its justifications?

Additionally, how do processes of adaptation, transformation, and recovery relate to one another? How are political, social, and spatiotemporal contexts considered? How can appropriate assessments translate into practical interventions? (Zeng et al., 2022).

The Russian Federation's full-scale invasion of Ukraine has become a hallmark of this era of instability, obliterating Europe's rule-based order established after World War II (Brovko, 2025). The extensive, deliberate destruction of the urban environment by high-precision, low-cost, and relatively low-tech drone weaponry has now reached unprecedented proportions, opening the gates to copycats and ensuring that no city can consider itself immune from analogous threats by nefarious actors. This dynamic has the potential to transform global political, social, economic, and environmental processes (Palekha et al., 2023).

Four years of daily attacks on Ukrainian cities have revealed the limits of their capacity for recovery and urban resilience (Kliuchko et al., 2024). The war has triggered a "domino effect" (Wamsler & Brink, 2016), in which the collapse of one system destabilises others, leading to cascading infrastructure failures (Yan et al., 2025). Failure of infrastructure foments social tensions, while economic stagnation creates urban instability, making long-term planning impossible (Kilcullen, 2012).

In response, we pair a resilience perspective, focused on absorptive, adaptive, and transformative capacities, with a bifurcation lens that identifies threshold conditions under which routine adaptation fails, thereby

clarifying when and how urban systems must stabilise, reconfigure, or transform in the context of polycrisis. This experience presents opportunities for a global re-evaluation of urban vulnerability and sustainability.

The city of Kherson is emblematic of multidimensional resilience under polycrisis: with pre-war economic stressors, a brutal occupation from March–November 2022, and a brief euphoria of liberation. This quickly gave way to constant shelling, destruction, and the infamous Russian practice of "Human Safari" (Tokariuk, 2025). Under such conditions, urban areas face simultaneous pressures from multiple, overlapping threats—military, climatic, social, and economic (Malchykova et al., 2025).

One of the key limitations of existing approaches is the insufficient attention to the spatial characteristics of urban systems, which undermines the capacity to make strategic decisions about their transformation within a polycrisis environment. At the same time, urban planning tools can indirectly influence emergency management and the effectiveness of crisis response by setting a long-term framework for resilience and creating conditions for more coordinated operational actions.

In this study, we conceptualise resilience and recovery as nonlinear, place-contingent processes shaped by cumulative damage, social disintegration, and ongoing threat. While we recognise the relevance of threshold and tipping-point thinking (Yi et al., 2025), our analytical emphasis is on resilience pathways—how cities manage to stabilise functions, rebuild capacities, and reconfigure identities under polycrisis. This framing anchors our empirical assessment and informs policy-relevant models of recovery tailored to spatial heterogeneity and institutional realities.

Accordingly, the main research questions are as follows:

- What morphological, functional, socio-demographic, institutional-economic, and environmental changes are occurring in urban areas under the influence of the polycrisis, and how is their identity being transformed?
- How do these changes reveal vulnerabilities and adaptive challenges that inform future models of urban recovery?
- How can the experience of Kherson be applied to develop approaches for the sustainable recovery of cities affected by military conflicts, environmental disasters, and social upheavals?

In view of the above, this study aims to explore how extreme violence interacts with pre-existing conditions of urban decay, inadequate infrastructure, and deteriorated public spaces and services, while conceptualising nonlinear models of urban resilience and recovery.

2. Theoretical Background

2.1. War-Driven Polycrisis: Urban Resilience and Recovery Pathways

Urban theory has increasingly examined resilience, adaptability, and recovery as core processes through which cities confront and reorganise themselves in the wake of crisis (Ibrahim et al., 2022). Armed conflict, as a driver of polycrisis, pushes urban systems to the brink, requiring innovative recovery scenarios to manage uncertainties across uneven geographies (Kittana & Meulder, 2019). The comparative experience of Sarajevo after the siege by the army of Republika Srpska (1992–1996), causing extensive destruction, isolation, and

humanitarian crisis (Martín-Díaz, 2021), Syrian cities such as Aleppo after infrastructure, heritage, and social fabric destruction (Dimelli & Kotsoni, 2023), and the radical transformations of Ukrainian cities in conflict zones and occupations (Malchykova & Pylypenko, 2023) shows that recovery rarely entails a return to the previous state, but rather a reconfiguration of adaptability, capacity, and resilience.

In this context, we highlight resilience as a dynamic trajectory of urban development that allows for the stabilisation of core functions (Meerow & Newell, 2019), the adaptive restoration of networks and services, and, where necessary, the transformation of urban systems to new functioning conditions (Lowe et al., 2024). Systematic reviews further operationalise this trajectory through three interlinked capacities—absorptive (stabilising critical functions), adaptive (reconfiguring and reconnecting services and networks), and transformative (shifting to new configurations under altered conditions)—which together structure measurable pathways of recovery (Zeng et al., 2022; Zheng et al., 2024). Recovery trajectories are nonlinear in both spatial and temporal terms due to existing vulnerabilities, varying degrees of impact, and differences in institutional and economic capacity. To determine when normal adaptation fails and why qualitative changes are likely, we combine the concept of resilience with bifurcation theory (Layek, 2015), since in complex socio-spatial systems, bifurcation dynamics explain the transition through a threshold that alters the system's behaviour under gradual parameter changes, leading to a different mode of functioning rather than a return to the previous state (Ikeda & Takayama, 2024).

In the context of urban development under constant threat, bifurcation complements the concept of resilience by providing the necessary operationalisation within the framework of war-induced polycrisis. The resilience concept forms a procedural logic (available pathways for absorption, adaptation, or transformation), while bifurcation dynamics explain the logic of thresholds, boundary conditions, and early-warning markers of the irreversible exhaustion of resilience potential. In practice, this combination enables controlled prediction of irreversible changes in functionality, the design of re-functionalisation or re-planning of systems, and the assessment of cascade risks, unevenness, and hysteresis. Applying this approach to Kherson under constant threat, we develop a differentiated vision that accounts for changes in social composition, collective trauma, and the evolution of the governance landscape (Antonenko, 2025). Cumulatively, such a strategy recognises irreversible changes where they exist, while outlining realistic, equitable, and sustainable paths to recovery in a polycrisis environment.

2.2. The Urban Context of Kherson: Preconditions, Transformations, and Challenges

Kherson is a city in southern Ukraine, located on the right bank of the Dnipro River, with a multilayered urban history. Founded in the 18th century, its spatial development was shaped by the military-strategic and industrial policies of both the Russian Empire and the Soviet Union. From the 1990s until the onset of the full-scale war in 2022, the city experienced economic decline, depopulation, and infrastructure degradation, which had already called into question its capacity for sustainable development (Ostapenko & Malchykova, 2025). The city's location along the Dnipro determined the logic of its transport and recreational development. Kherson's urban structure reflects Soviet zoning principles: the central area comprises mixed-use development with administrative, educational, and cultural institutions, while industrial enterprises and residential neighbourhoods occupy the periphery. Most residents live in prefabricated multi-storey housing blocks built in the 1970s and 1980s, particularly in the Tavriyskyi, Pivnichnyi, and Korabel districts (Department of Architecture and Urban Planning of the Kherson City Council, 2013).

Following its occupation in March 2022 and subsequent liberation in November 2022, Kherson has remained under constant shelling and military threat, creating a unique context of continuous instability. Such sustained pressure has led to the destruction of housing and critical infrastructure, mass evacuation, and profound socio-spatial disintegration. Under these conditions, the question of urban resilience has acquired an existential dimension—not only in terms of the city's capacity for recovery, but also as a search for a new model of urban existence.

Two residential districts—Tavriyskyi and Korabel—were selected for comparative analysis as representative cases of urban resilience under wartime conditions (Figure 1). Tavriyskyi has a more developed social infrastructure and, prior to the war, served as the urban core for the middle class. Korabel, by contrast, is a district with an industrial past, located near a shipbuilding plant, characterised by a lower density of social services but a high level of local self-organisation. Both areas consist predominantly of prefabricated multi-storey buildings, which makes them comparable in terms of physical resilience, energy efficiency, and social composition. The varying extent and nature of destruction across these districts offer an opportunity to examine the variability of urban resilience within a single city. The district level is chosen as the main analytical scale because it is at this micro-territorial level that residents directly experience the consequences of conflict and that both formal and informal adaptation strategies take shape. At the same time, contemporary studies of urban functional resilience reveal a pronounced scale imbalance: district-level data are almost entirely absent, while most information is aggregated at the city or administrative region level. This lack of micro-scale research is critical, since districts constitute the primary living milieu in which resilience and adaptability become directly observable.

In this study, the term *district* is understood as a spatial-social unit that encompasses: (1) physical infrastructure (housing stock, roads, and networks); (2) social fabric (demographics, communities, and institutions); (3) functional linkages (access to services, transport, and communications); and (4) levels of vulnerability and adaptive capacity. This approach enables assessment not only of the district's physical resilience but also of its social viability as a system responding to external threats, accounting for the unique role of persistent military turbulence and the microspatial mechanisms of adaptation that remain invisible at larger administrative scales.

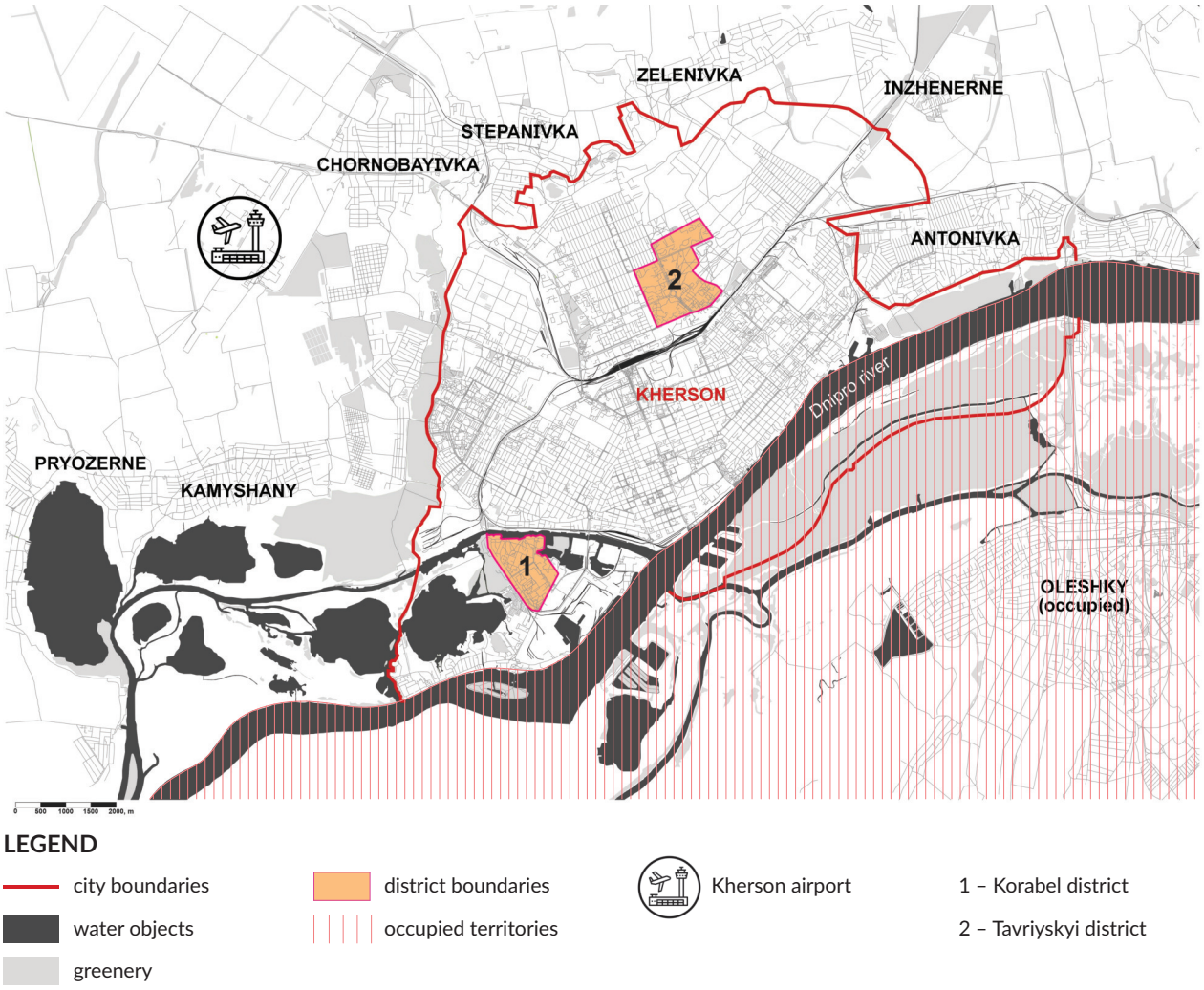

Figure 1. Location of research areas in Kherson.

3. Methodology

The research methodology is based on a multi-level qualitative-empirical approach aimed at studying nonlinear socio-spatial transformations of urban systems in conditions of polycrisis. This approach is justified by its ability to combine the analysis of physical destruction and erosion of the social structure, complex processes that one-dimensional methodological frameworks are often unable to adequately reflect in areas of active conflict. The Tavriyskyi and Korabel districts were selected by focused sampling as typical post-Soviet residential morphological units with a high level of pre-war structural dependence (Gnatiuk & Kryvets, 2018). Their inclusion is based on their typicality, scale, and levels of physical and social deterioration, making them representative for studying the limits of urban resilience in the Ukrainian context. The research design comprised the following stages: data collection, organisation, analysis, and interpretation, considering the limitations arising from ongoing military threats and partially/periodically limited access to the territory.

Primary qualitative data were obtained through semi-structured interviews with internally displaced persons, community leaders, and municipal officials. This method was prioritised to capture the "human dimension"

of resilience, documenting adaptive practices and informal institutional responses that are absent from formal datasets. Additional documentary sources were used, including municipal reports and analytical materials from civil society organisations. An important methodological core was the reflective involvement of the authors: a five-month stay under occupation (2022) and subsequent field visits (2023–2025) provided privileged access to informants and a deep understanding of urban trauma. This positioning is critical to ensuring data reliability in a limited information environment. Spatial data on destruction were obtained from publicly available satellite imagery and verified through local communication. This method provides objective evidence of "urbicide" and infrastructure degradation in cases where ground surveys are dangerous. Data gaps and uncertainties, especially at the district level, constitute a methodological limitation of this study. To overcome the fragmentary nature of wartime statistics, a triangulation strategy was applied, using secondary sources as contextual layers to verify the identified patterns. This allows for the maintenance of conceptual validity and empirical reliability despite gaps at the micro level.

The collected materials were organised into analytical blocks to assess resilience, encompassing morphology, mobility, functionality, critical infrastructure, the water-green framework, public spaces, identity transformations, socio-demographic characteristics, and institutional and economic resilience (Antonenko, 2025). The methodology for analysing and interpreting data combines spatial analysis (GIS layers on the destruction of residential buildings and damage to infrastructure) with socio-demographic analysis (assessing changes in population composition, mobility, and access to essential services) and institutional assessment (local government responses, local initiatives, horizontal networks, and community self-organisation resources). This structure enabled the integration of spatial data with qualitative narratives that reflect the complexity of urban sustainability amid ongoing precariousness, constant attack, and polycrisis.

The main method used was situational analysis, which integrates spatial and institutional data to map, in real time, the interactions between internal and external stressors and describe specific problems in the city's functioning. The results were interpreted through the lens of stability theory and bifurcation dynamics, providing a conceptual understanding of nonlinear recovery trajectories. The methodology generally emphasises situational adaptation and multi-source verification, rejecting utopian recovery models in favour of a pragmatic assessment of urban governance in conditions of extreme uncertainty and social exhaustion.

In this study, the mapping method functions not only as a tool of visualisation but also as an analytical instrument for operationalising the concept of nonlinear resilience at the micro-territorial level. The overlay of layers of morphology, functional structure, greenery, public spaces, and the transport network, in correlation with localised threats and damages, allows for identifying and visualising spatial disproportions, "nodes of fragility," and zones of potential adaptation. Mapping serves as a methodological bridge between the theory of polycrisis and empirical data, illuminating the interactions among urban environment components under wartime turbulence and outlining spatially differentiated recovery trajectories.

4. Results and Findings

4.1. Spatial Urban Resilience of Residential Districts in Kherson

4.1.1. Morphological "Irreversibility" and Trajectories of Urban Development

The morphology of Kherson's residential districts, shaped during the Soviet period, is a key factor behind the city's heightened urban vulnerability. The spatial structure of Tavriyskyi and Korabel, developed within the urban paradigms of the 1970s–1980s, relied on standardised housing construction and rigid functional zoning aimed primarily at rapidly providing apartments for the population. The combination of prefabricated multi-story buildings, large unprogrammed open spaces between them, and limited opportunities for reconstruction due to apartment privatisation resulted in structural inflexibility. The low prewar morphological resilience was manifested in the physical deterioration of the housing stock, demographic ageing, degradation of social infrastructure, and spatial non-inclusiveness.

After 1991, morphological transformations were minor, limited to partial thermal modernisation, small-scale extensions, and interior renovations. An additional vulnerability stemmed from the non-inclusive nature of external and internal spaces (including limited accessibility to upper floors during power outages) and the low energy efficiency of high-rise buildings, which amplified the effects of climate change.

During the war, low morphological adaptability has severely constrained the city's capacity to respond to shelling, evacuation challenges, logistical disruptions, and the functioning of emergency services (Meuser et al., 2023). Since the onset of intensive attacks, the urban fabric has undergone rapid and large-scale changes: approximately 60% of buildings in Tavriyskyi were damaged, and in Korabel, the figure has reached nearly 100%, due to proximity to the port, industrial zones, and the frontline. Following the destruction of the Kakhovka Reservoir—an instance of weaponised water infrastructure—Korabel was almost completely flooded, causing significant damage to buildings, loss of critical infrastructure, and extensive ecological degradation (Hirniak, 2025). The district's morphology, which once possessed some transformative potential due to its compact size, has now lost functionality; the idea of restoring it in its original form grows increasingly untenable as reconstruction becomes technically complex, costly, and strategically questionable (Figure 2).

The existing morphological and spatial configuration—defining the layout of critical infrastructure and road networks—combined with zonal patterns of destruction and the degradation of inter-building spaces, creates preconditions for nonlinear territorial development within a constrained set of conditions. This allows outlining three potential directions for urban renewal:

a) repair and restoration of the least damaged and most densely populated buildings;
b) selective reconstruction of damaged blocks with adjustments to height, floor plans, and ground-floor functions;
c) densification and redevelopment guided by new planning concepts oriented toward the needs of all social groups.

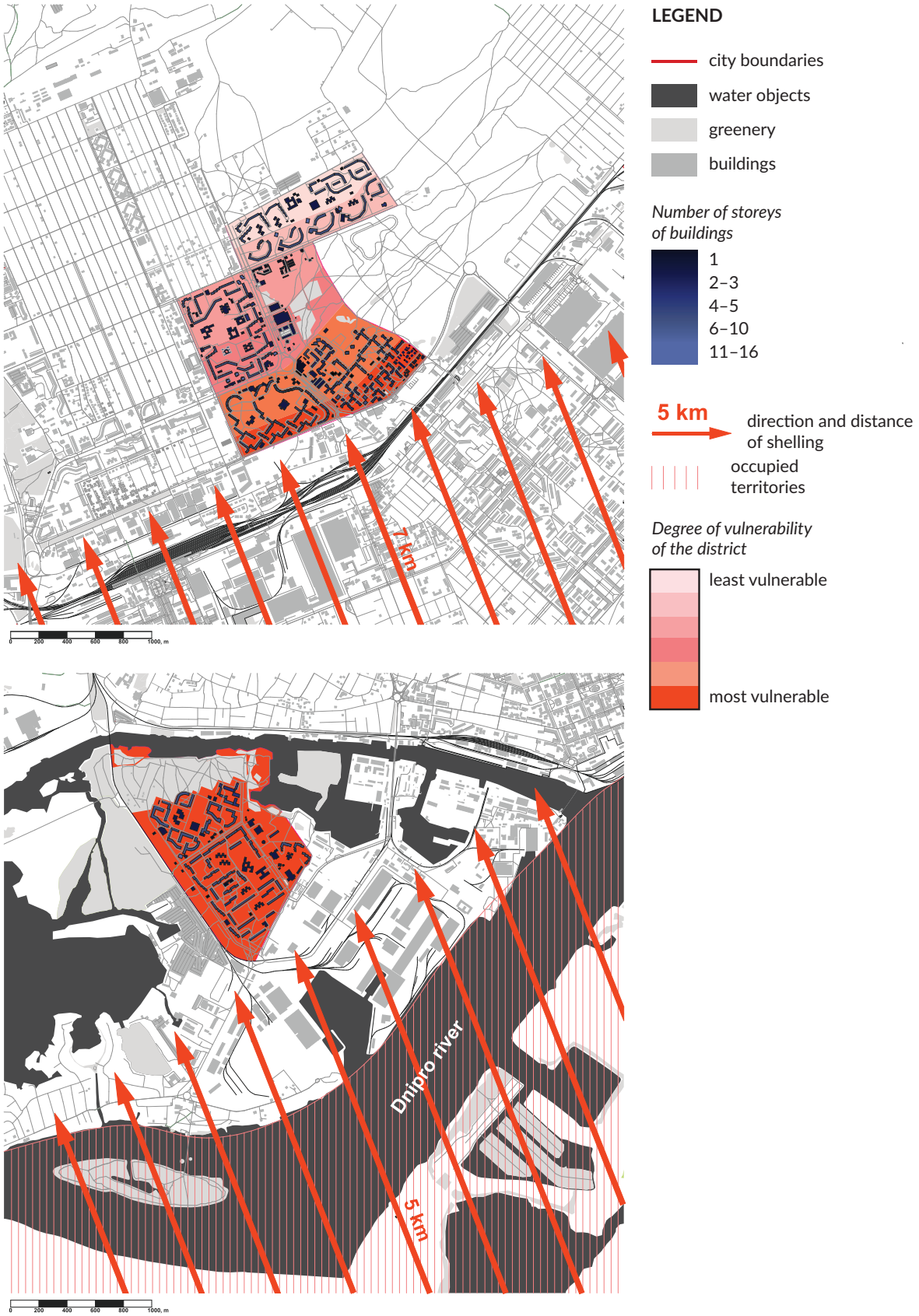

Figure 2. Morphology of Tavriyskyi and Korabel districts under conditions of polycrisis.

4.1.2. Logistics and Transport Structure: Dynamics and Development Scenarios

As of 2022, Kherson's transport system already required fundamental rethinking and restructuring. Excessive commercialisation of public transport, poor route coordination, the absence of cycling infrastructure, and the dominance of private vehicles had generated chronic disorder within the city.

Under wartime conditions, the transport system is being restructured and assumes existential significance (Rossolov et al., 2025), with its primary function being to ensure evacuation and access to essential resources. Private and commercialised public transport, which previously constrained effective mobility in the pre-war city, now provides the most reliable means of movement due to its speed, reduced waiting times, and lower risk of exposure arising from lower passenger density. The number of available public transport routes has been reduced, depending on factors like road quality, route length, and the likelihood of being targeted by occupiers. Similar transformations are observed in the pedestrian infrastructure within districts: routes are defined as the shortest paths to essential facilities or public transport stops, integrate access to shelters, and ensure an adequate level of inclusivity, which is critical given changes in socio-demographics.

Tavriyskyi, located in the northwest of Kherson near key transport hubs, demonstrated relative resilience and adaptation in its transport system, effectively supporting evacuations, humanitarian aid deliveries, and the functioning of emergency services. In contrast, Korabel, which is connected to the rest of the city by a single arterial road, has lost its capacity for self-recovery due to a vulnerable transport network. Following the Kakhovka Reservoir disaster caused by the destruction of the Nova Kakhovka Dam, the district was temporarily isolated, and damage to the bridge led to complete isolation, necessitating the organisation of an urgent, forced evacuation of residents (Figure 3).

The existing road network, reliance on private transport, and residents' experience of adaptation under wartime conditions provide a foundation for developing new flexible and resilient transport solutions that address the pre-war vulnerabilities of logistical systems.

The restoration will require comprehensive reconstruction and should include:

a) safe and inclusive mobility, encompassing road repairs, the creation of pedestrian-oriented corridors, low-floor vehicles, and stops adapted to the needs of vulnerable groups;
b) sustainable transformation and the development of a hybrid transport model that integrates public, private, and emergency transport with flexible routing for rapid crisis response, including the design of new logistical schemes and the incorporation of bicycle and electric transport potential;
c) crisis preparedness, including the planning of evacuation routes and logistical scenarios to ensure prompt emergency response.

Figure 3. The transport situation in the Tavriyskyi and Korabel districts under conditions of polycrisis.

4.1.3. Critical Infrastructure and Functional Status: Vulnerability, Adaptation, and Prospects for Recovery

The functional structure of Kherson's districts during the Soviet period was shaped by the principle of providing a minimally necessary yet formally sufficient set of facilities. Urban planning was based on a three-tier service model; however, due to chronic underfunding, many social infrastructure projects were never completed. As a result, many districts were left without a basic range of public buildings. Since the 1990s, this deficit has been partially compensated for by the development of private entrepreneurship, which has responded more flexibly to residents' everyday needs.

Critical infrastructure facilities were designed with reserve capacity; however, low construction quality led to numerous failures already in the post-Soviet period (Ponomaryova & Ryan, 2021). Even before the war, water supply and sewage networks were in poor condition, and stormwater drainage systems failed to meet technical and sanitary standards.

Following the de-occupation of the city, sustained artillery and missile attacks, and the artificial disaster caused by the Kakhovka Reservoir disaster, the Korabel suffered extensive damage to its engineering infrastructure. At the regional level, critical infrastructure remains largely dependent on centralised sources, complicating local management, autonomous operation, and rapid response to damage. Under wartime conditions, the provision of basic services, the partial stability of critical infrastructure, and the uninterrupted supply of essential goods and services have been severely undermined. The water, sewage, and electricity systems were the most severely affected, resulting in the district's functional isolation. Prior to evacuation, utility services were provided only intermittently. In Tavriyskyi, the situation is less critical; nevertheless, the centralised electricity supply remains highly vulnerable. Resilience hubs equipped with generators offer only partial relief and cannot meet the needs of all residents. Private generators offer limited autonomy and are accessible primarily to economically stable households. Centralised heating systems are inefficient under low occupancy, particularly when fewer than 30% of apartments are occupied, making their operation economically unjustifiable. The gas supply remains functional, which creates additional risks for residential buildings during shelling, although it may also serve as a backup heating source. The civil defence alert system is fragmented. Radio broadcasting is absent, while internet connectivity is unstable and entirely dependent on electricity, with no backup channels.

Kherson's critical infrastructure requires urgent modernisation and protection without waiting for the end of hostilities. A key stabilisation strategy has been the rethinking of centralised critical infrastructure. The main priorities include:

a) decentralisation—the transition to distributed energy resources, modular microgrids, and local water supply systems, which would also ensure the autonomy of critical facilities;
b) infrastructure redundancy—the creation of alternative supply channels, backup systems, and mobile distribution points to reduce dependence on trunk networks;
c) public participation and local governance—strengthening the role of local communities and self-organisation initiatives as mechanisms for adaptation and for maintaining the functional stability of critical infrastructure.

The modernisation of critical infrastructure remains fragmented, while recovery measures are poorly coordinated and largely ineffective. The lack of reserve capacity and systemic redundancy, together with continuous shelling, high levels of centralisation, limited adaptability, and outdated technologies, significantly increases the vulnerability of infrastructure systems and accelerates their further degradation. This deepens the humanitarian crisis through deteriorating living conditions, making a return to the pre-war functional model impossible. At the same time, analysing the preservation of critical infrastructure systems and evaluating the effectiveness of fragmented experimental solutions may provide a foundation for post-war innovative modernisation, including the implementation of energy-efficient technologies, digital monitoring, and intelligent resource management systems.

Regarding service functions, the war has significantly weakened functional interconnections within the districts: some facilities have been destroyed, while others have ceased operations (Figure 4). Tavriyskyi has largely retained the essential facilities that meet the basic needs of residents—shops, pharmacies, several medical centres, and a market. During the occupation, small-scale, often mobile retail outlets and informal services, despite the risks of criminalisation and legal uncertainty, formed an elementary grassroots economic infrastructure that continued to supply the population with essential goods and services (Mikhalkov, 2025). Spontaneous street-based economic activity thus remains a crucial element of a social "safety buffer" during crises. Under conditions of intense missile attacks, underground spaces have increasingly been repurposed to accommodate vital services; in particular, projects for underground schools, medical facilities, and social hubs are being implemented. The situation in Korabel followed a similar trajectory but was further complicated by spatial isolation, a lower density of functional facilities, and the presence of industrial heritage. The ingenuity and solidarity of the Kherson community were especially evident after the Kakhovka Reservoir disaster, when, within a short period and under acute crisis conditions, street kitchens emerged to temporarily compensate for the loss of centralised services (Hirniak, 2025). Nevertheless, forced evacuation ultimately rendered even basic service provision impossible.

The functional provision of the districts demonstrates varying levels of resilience, largely determined by the capacity and resources of local businesses, which can act as key drivers of recovery. The most promising forms of microbusiness and social entrepreneurship are highly adaptive, mobile, and community-oriented, reflecting the new gender and age composition of the population (Belitski et al., 2024). These changes provide a basis for a comprehensive rethinking and the formation of a new functional structure of the territories, outlining potential trajectories for recovery and development:

a) functional revitalisation—restoration and expansion of key functions with priority given to local, inclusive, and transformative facilities;
b) mobile and temporary solutions—deployment of mobile clinics, social hubs, and dual-purpose shelters for rapid response to crises;
c) integration of the informal economy—legalisation and support for street trade, crafts, and local services as sources of employment and social stability;
d) formation of new centres of attraction—creation of multifunctional public spaces on the sites of destroyed or abandoned facilities, capable of functioning as market–social hybrids that combine commerce, services, recreation, and community support.

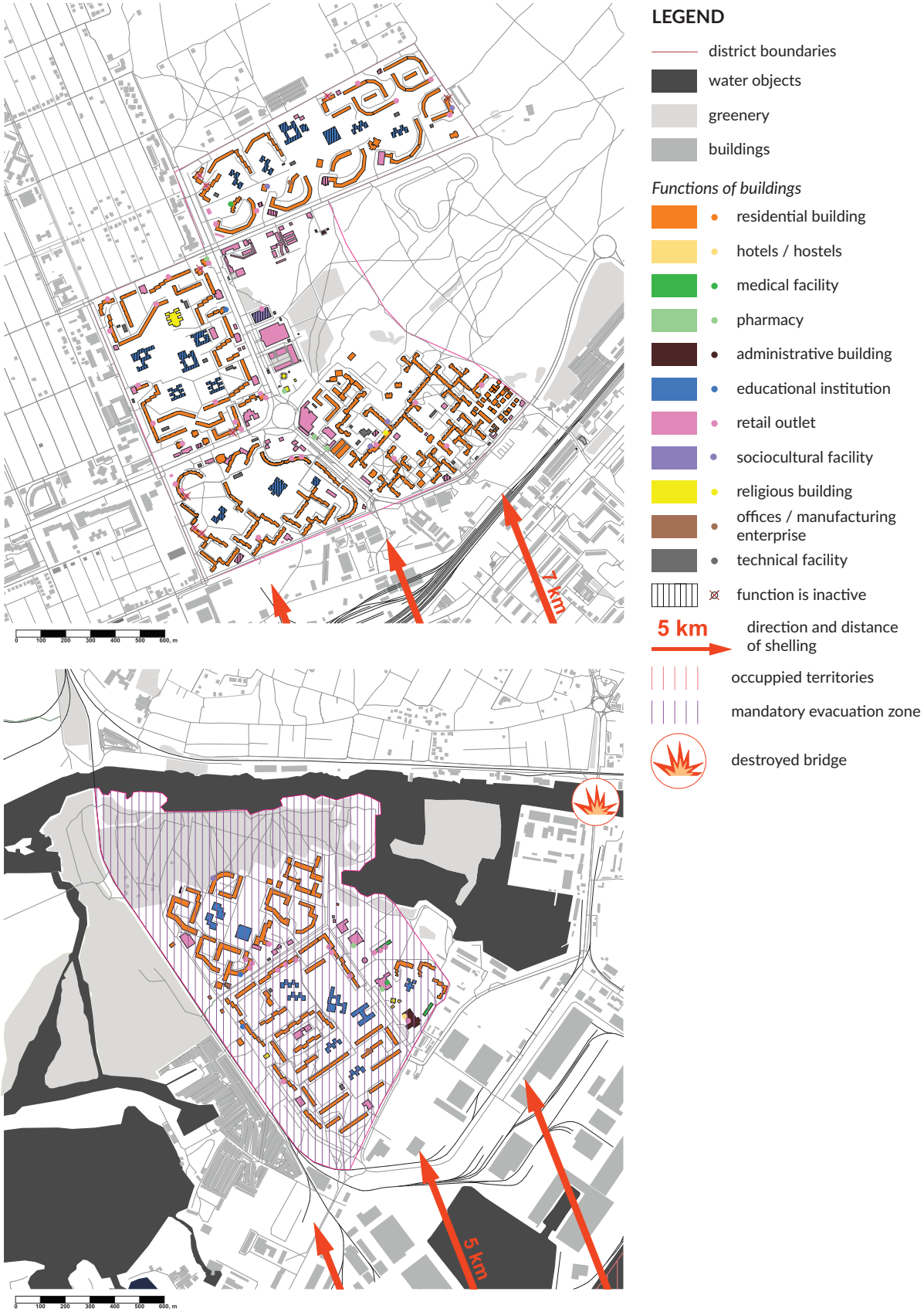

Figure 4. Functional content of Tavriyskyi and Korabel districts under conditions of polycrisis.

4.1.4. Blue-Green Infrastructure and Public Spaces: Ecological Vulnerability, Climate Adaptation, and Development Potential

The design of Soviet residential areas envisioned extensive blue-green infrastructure (BGI) and the integration of greenery into broader urban and suburban ecosystems. BGI was integrated with transport and functional planning, forming public spaces for daily use. On the island, the Korabel waterfront and a nearby small island served recreational purposes, featuring a water park, beach, and zoo. In Tavriyskyi, the BGI remained incomplete: the central park was never constructed, and greening efforts were fragmented. This led residents to plant trees and maintain their own front gardens, resulting in a significant increase in green space over the course of three decades. After 1991, the planned park site became a wasteland, later reorganised into a landscape park. Some green corridors were built over, and the lack of connectivity with larger natural areas limited ecological circulation, self-purification, and climate regulation. Until 2022, greening efforts in both districts were uneven, with the main focus on courtyards and school grounds. Functional diversity was low, and some green spaces were privately owned and inaccessible, limiting public use.

Kherson is exposed to extreme weather events annually, including dust storms, droughts, squalls, and freezing rain, which are expected to intensify due to climate change (Ballarin et al., 2025). The lack of shaded areas, water-retentive vegetation, and adaptive infrastructure such as canopies, awnings, and green walls reduces thermal comfort and poses significant health risks, particularly for vulnerable groups. Overheating has become systemic and cannot be mitigated by existing measures. Moreover, the prevalence of impervious surfaces contributes to flooding during heavy rainfall, soil erosion, and pavement degradation.

War has irreversible consequences for the environment and exacerbates an already vulnerable situation with respect to climate adaptation. Soil, air, and water are polluted with chemicals; ecosystems are degraded; biodiversity is lost; and vegetation is destroyed, all of which have negative repercussions for human health (Leal Filho et al., 2024). The maintenance of green spaces is fragmented and predominantly carried out by residents. Municipal services provide only basic upkeep, and in extreme danger, there is no systematic intervention. The complex and intensive deterioration of living conditions contributes to a hazardous epidemiological situation, thereby increasing the risk of chronic diseases (Figure 5).

Figure 5. Water-green framework and public spaces of Tavriyskyi and Korabel districts under conditions of polycrisis.

In Korabel, the situation was further exacerbated by flooding following the Kakhovka Reservoir disaster, which destroyed a substantial part of BGI (Figure 6). Many green and public areas have become unusable. The district currently faces both transportation and environmental isolation, and its water and green infrastructure have deteriorated significantly. Green spaces have been destroyed or inundated and are not currently maintained. Korabel has reached a critical threshold, where the combined effects of flooding, destruction, and pollution make restoring its BGI possible only through a comprehensive environmental audit, soil remediation, and the establishment of entirely new, climate-resilient urban ecosystems.

Public spaces in Tavriiskyi are used only to a limited extent, while significant portions of natural landscapes remain inaccessible due to mined areas. Some socio-cultural functions have shifted to basements and underground shelters, where exhibitions, concerts, library activities, and school classes continue, providing a limited but vital continuation of social and cultural life. However, in the event of a ceasefire, the district retains potential for ecosystem restoration and considerable spatial opportunities for climate adaptation. Active community engagement, including urban gardening during wartime, combined with systematic institutional support, can serve as a foundation for developing sustainable, climate-resilient, and socially engaged urban districts (Kononenko & Trusii, 2025).

Figure 6. Consequences of the Kakhovka reservoir disaster for the Korabel district under conditions of polycrisis.

4.2. Socio-Demographic Assessments and Institutional-Economic Resilience

Socio-demographic factors and institutional-economic resilience form the foundation for urban sustainability (Giulia, 2023). They determine not only the quality of social ties, the level of community cohesion, and the psycho-emotional well-being of residents, but also the capacity of urban areas to maintain essential services, respond to crises, and recover under conditions of limited human, financial, and administrative resources (Soldak et al., 2024). In contexts of war, occupation, ecological disasters, and social exhaustion, this component of resilience becomes critical for the survival of urban structures (Reznikova & Korniievskyi, 2024).

Both studied districts are experiencing a profound demographic crisis, driven by mass population outflows, mobilisation, and resident losses. The population, particularly children, youth, and working-age adults, has declined significantly, while the proportion of elderly residents and people with disabilities requiring additional support has increased. The reduction in economically active residents undermines the local labour market and community self-organisation, while the loss of professionals in healthcare, education, and the public sector diminishes service quality and complicates post-crisis recovery.

The integration of local communities has been accompanied by a breakdown of horizontal ties—between neighbours, families, and professional groups—and the disappearance of everyday practices of social interaction. The social environment has become fragmented, with new groups forming that lack a strong emotional connection to a particular place, leading to a decline in local identity. In Tavriyskyi, the potential for local agency is maintained through the efforts of active residents, whereas in Korabel, evacuation and transport isolation have effectively deprived the community of human resources, rendering basic urban functions unviable.

The institutional structure of both districts is fragmented and vulnerable. Housing associations remain the only effective forms of local governance. The absence of integrated development strategies, cross-sectoral coordination, and digital management tools diminishes the capacity for adaptation. Local administrations operate under constant threat, relying on community and volunteer organisations to compensate for limited funding and staffing shortages (Keudel et al., 2024).

The economic foundation of districts during wartime has been destroyed or severely weakened by business closures, bankruptcies, relocations to safer areas, widespread job losses, and a general decline in household incomes (Zhalilo, 2023). Microbusinesses and the informal economy have become the primary sources of employment; however, they are unstable, under-supported, and often operate outside the legal framework. The institutional and economic resilience of the studied areas is critically low, though it exhibits varying potential for recovery.

Tavriyskyi, with its preserved social fabric and active local initiatives, has the potential for gradual recovery through the support of condominium associations, the development of microbusinesses, and resident involvement in management. Korabel, by contrast, requires a new institutional architecture, an economic restart, and integration into the urban system via targeted recovery and reconstruction programmes.

War, occupation, flooding, destruction, displacement, and isolation have generated both individual and collective psychological trauma, manifested in chronic anxiety, depression, and frustration—particularly

among children, the elderly, and women—as well as loss of trust in institutions, feelings of powerlessness, social apathy, disruption of intergenerational ties, breakdown of family structures, and loss of social capital. Collective trauma generally reduces the capacity for collective response, recovery, and community participation in both districts during crises (Ramsay, 2022).

Conditions of polycrisis necessitate deep social rehabilitation, without which no urban model can be sustainable in the long term.

4.3. Spatial and Social Identity: Between Loss, Transformation, and the Search for a New Subjectivity

The identity of an urban district is reflected in spatial forms of residents' interactions with space, encompassing everyday practices, social ties, cultural codes, and collective memories (Ziyaee, 2018). In the pre-war period, the studied districts underwent a latent transformation of post-Soviet identity: despite the preservation of spatial frameworks, symbolic cohesion was eroding—Soviet symbols disappeared, and thematic bas-reliefs and monumental compositions were dismantled or destroyed. Changes in everyday practices influenced the morphology of development, public spaces, and functional content, resulting in the visual heterogeneity characteristic of post-Soviet cities. Over time, the public's demand to reject the "Soviet" was reflected in legislative initiatives aimed at decommunization, desovietization, and the de-imperialization of urban space (Lazarenko, 2022).

In 2022–2023, districts experienced deep, destructive impacts that affected their symbolic structure and residents' modes of self-identification. These changes were especially pronounced during the Russian occupation of Kherson, marked by the deliberate replacement of Ukrainian meanings with Russian ones: renaming of streets, monument destruction, imposition of Russian cultural agenda, and the use of public spaces for propaganda (Homaniuk & Gabowitsch, 2024). Such practices intensified the erosion of local self-awareness, disrupted sociocultural continuity, and inflicted deep trauma on collective memory.

New symbolic markers of urban resilience began to emerge in the urban environment—patriotic murals, signs of resistance, restored facades, and well-kept courtyards. These elements reflect survival and solidarity, forming a new urban language rooted in experiences of war, loss, and resistance.

In this context, Tavriyskyi emerges as a space of both resilience and vulnerability. Once seen as a peripheral yet stable district, it is now perceived as relatively safe compared to the city centre. However, this shift has not resolved deep-rooted structural issues, including economic decline, weak social infrastructure, and a lack of cultural anchors. Mass migration has eroded traditional social ties, yet a core of active residents—apartment owners, homeowners' association members, and garage cooperative members—continues to demonstrate self-organisation. They invest personal resources in maintenance, courtyard improvements, and shared spaces. These practices foster a new communal identity and support emerging forms of local engagement. In Korabel, the destruction of infrastructure, housing, and water systems, coupled with forced mass evacuation, has led to its stigmatisation as a "disaster zone" or "enclave of isolation," deepening social fragmentation and alienation.

However, even during crises, new foundations of local identity have emerged—shared experiences of survival, mutual aid, volunteer efforts, and support for vulnerable groups. The district's space has acquired a musealised character, with inscriptions documenting catastrophe, loss, evacuation, and hopes for return. The trauma of

losing one's home has entered the collective memory of displaced residents. These practices of solidarity and interaction may serve as a basis for revitalising community life.

5. Discussion: Bifurcation Dynamics and Nonlinear Models of Resilience, Adaptation, and Recovery

This study demonstrates that the recovery of urban environments in a polycrisis is a multidirectional, contradictory process. Rather than a linear "return" to a prior equilibrium, post-catastrophic recovery entails constructing a new urban order in which trauma, survival practices, and the appetite for change become the substrates of a reconfigured reality (Sengupta, 2023). Foregrounding nonlinear models of resilience, adaptation, and recovery shifts the analytical lens from cumulative damage to thresholds, feedbacks, hysteresis, and cascades. Debates on crisis decision-making highlight how, at such critical junctures, governance, spatial organisation, and social relations must be recomposed to sustain functionality and dignity (Jafar, 2025). This approach moves beyond "domino-effect" framings to trace how systems toggle between distinct operational regimes.

The spatial and social shifts in Kherson resulting from war, occupation, and destruction demonstrate the interaction of absorptive, adaptive, and transformative capacities, leading to an urban order moving toward an unstable yet functionally viable configuration that combines temporality and resilience. Absorptive capacity manifests itself in maintaining basic functions despite challenges, preventing the complete collapse of everyday life. Adaptive capacity is manifested through the reconfiguration of urban logistics and service networks, which can take hold and influence the post-war structure of the city. Transformational capacity is most evident in the most damaged areas, where environmental and infrastructure crises and depopulation render previous models of governance impossible and give rise to new forms of local identity and self-organisation. Taken together, this shows that bifurcation dynamics manifest themselves not only in destruction but also in the situational reformatting of the urban order, where instability becomes a tool for renewal.

The three systemic capacities of the city are manifested through four interrelated dimensions. The morphological-spatial dimension reflects the erosion of the urban tissue, combined with environmental degradation, and characterises the limits of the city's absorptive capacity to maintain its basic spatial infrastructure. Functional and logistical reflect the processes of functional erosion and the cyclical "reassembly" of services, networks, and administrative capacities, which fragment everyday life. The socio-demographic dimension becomes an arena of transformational capacity, where new social identities and roles emerge, aimed not at reproducing stability but at maintaining survival and minimal coordination. The institutional and economic dimension captures the weakening coordination between governance and market mechanisms, which directly undermines the system's ability to provide basic services, leading to threshold effects and potential bifurcations. Collectively, these dynamics disrupt the symbolic geography and generate new markers of memory, resistance, and survival.

The trajectory of spatial sustainability of cities in conflict zones loses its linearity, consistency, and predictability when a complex system of transformations is characterised by:

a) irreversibility of physical destruction—the scale of damage exceeds the capacity for local restoration;

b) loss of functional integrity—disappearance of key services, infrastructure, transport connections, and administrative capacities;
c) social disintegration and disorientation—mass migration, critical shifts in age-gender structure, disruption of traditional ties, emergence of new crisis-driven forms of identity, and rising collective fear and uncertainty about the future;
d) exhaustion of adaptive potential—local initiatives and external support are no longer sufficient to compensate for systemic losses and ecological irreversibility;
e) transformation of the symbolic language of space—emergence of new value markers that document experiences of catastrophe, resistance, and survival, replacing previous ones.

These markers show that the urban system is not returning to its pre-war state but is recreating itself in a new hyper-fragmented and structurally disintegrated configuration. The Kherson experience is transferable to cities affected by military conflict, environmental disasters, and social upheavals through principles that respect nonlinearity and spatial differentiation: phased, vulnerability-informed recovery with practical approbation; adaptive governance that iterates with feedback; ecological rehabilitation aligned with risk governance; restoration of functional connectivity via resilience hubs; co-production of memory and identity in public space; and spatial justice to prevent the lock-in of uneven recovery.

Future research should deepen the analysis of bifurcation dynamics by developing predictive models that integrate spatial heterogeneity, network fragility, and socio-institutional feedback. Comparative studies across conflict-affected cities could refine indicators of nonlinear resilience and identify early-warning thresholds for cascading failures and bifurcation points.

6. Conclusion

The study proposes a new approach to assessing urban spatial resilience in the context of polycrisis, defined as catastrophic events that undermine the functioning of urban systems and nullify their adaptive capacity. An analysis of the resilience of two residential districts in Kherson during the war reveals new dimensions of urban instability and reconsiders post-catastrophic recovery through the lens of nonlinear urban development, focusing on key dimensions that define urban resilience.

The study examines the (im)possibility and (un)necessity of restoring pre-crisis functionality even after major threats have subsided. The concept of resilience and adaptive potential should consider:

a) morphological flexibility—the ability to replan and reorganise urban spaces during crises, adapt them to new functions, and compensate for spatial constraints;
b) decentralised infrastructure and hybrid mobility—ensuring the autonomy of critical services, alternative supply and evacuation routes, and the independent functioning of district segments regardless of centralised networks;
c) functional diversity and inclusivity—ensuring that public spaces support the quality of life of local communities, meet urgent needs, and provide protection;
d) community engagement and local governance—fostering social resilience through self-organisation, mutual aid, and adaptive management in affected districts;

e) economic capacity—ensuring sufficient resources to maintain exchange and overall urban system functionality.

Rethinking urban functions in the context of catastrophic events establishes a new approach to resilience that accounts for spatial destruction, community fragmentation, resource scarcity, and collective trauma. Instead of restoring pre-war structures, the study proposes a selective implementation of nonlinear strategies to stabilise the most vulnerable elements of the urban environment.

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Conflict of Interests

The authors declare no conflict of interests.

Data Availability

Due to the nature of the research, data sharing is not applicable to this article.

LLMs Disclosure

During the editorial phase, digital tools were employed to enhance the clarity and style of the manuscript. Specifically, Microsoft Copilot (GPT-4) was utilised for stylistic refinement and ensuring alignment with academic conventions. Grammarly was applied for final language editing, including grammar, punctuation, and stylistic consistency.

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