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A Spatial Forensics Framework for Assessing Direct Impacts and Ambient Conditions of Warfare: Pilot Methodology and Field Validation in Lviv, Ukraine.

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SUMMARY

Significant infrastructure damage resulting from kinetic attacks in war is a clear consequence of hostilities. Typical impacts include building collapse and damage to load-bearing structures caused by missile and drone strikes. However, conventional visual assessment using digital cameras has limitations in detecting small-scale defects, including cracks in concrete and panel structures, material delamination and chipping, damaged joints, and other subtle changes. This problem is particularly important for assessing the broader impact of military operations on civilians. Direct damage, combined with disruption of engineering networks, power outages, loss of heating during cold periods, exposure to moisture and precipitation, and limited maintenance opportunities, can accelerate building deterioration and adversely affect living conditions. This paper offers a pilot methodology using spatial forensics to document how war can weaponize domestic spaces over time, investigating the combined effects of direct explosive impacts and indirect environmental stressors on residential buildings in Lviv, Ukraine. Focusing on Soviet-era "Khrushchevka" housing blocks affected by Russian attacks, the research combines terrestrial laser scanning and thermal imaging to document spatial deformations and anomalous heat-loss patterns. To contextualize these observations, the study integrates air-raid alarm notifications, electricity outage records, and extreme weather conditions. Saaty's Analytic Hierarchy Process is used to structure and weight these temporal indicators to assess how they compound the physical hardship of civilian domestic life during wartime. By integrating spatial, thermal, infrastructural, and temporal data, the study proposes a framework for assessing the cumulative environmental exposure to wartime impacts on residential infrastructure and civilian living conditions.

Keywords: Spatial Forensics; Terrestrial Laser Scanning; Thermal Infrared Imaging; Analytic Hierarchy Process; Mass Housing; Open-source Visual Investigations; Ukraine;

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Introduction

Established practices for documenting civilian harm in conflict zones are effective in assessing damage from kinetic attacks, such as building collapses due to missile strikes, but they frequently overlook less critical and less visible structural damages. Small-scale defects, including cracks, material delamination and chipping, local deformations, joints damage and other subtle changes in structural conditions, may remain undetected through conventional visual documentation. Also overlooked are the ambient dimensions – temperature, light, and sound also shape urban living, and when conflict interferes with these conditions, they become continuous registers of violence.

Some methodologies have been developed to render these ambient conditions visible, such as using satellite imagery to visualize prolonged blackouts or track urban combat movements and industrial activities through thermal anomalies (Devine & van der Merwe, 2022; Dingemanse et al., 2026). Infrared thermography is also widely used for non-destructive assessment of building envelopes, allowing the detection of thermal irregularities associated with insulation defects, thermal bridges, moisture and air leakage (Kirimtat & Krejcar, 2018; Nardi et al., 2018). Meanwhile, soundscape recordings have been used to explore the environmental impacts of the war (Clark, 2026). While many of these investigations offer insights to the war's effects on the country's economy, ecology, military, and infrastructure, less attention is given to the way these ambient phenomena interface with domestic spaces during active conflict.

During the winter of 2025–2026, targeted attacks on Ukraine's energy grid caused recurrent disruptions to electricity and heating services, including in Lviv. This precarity is especially amplified for residents of "Khrushchevkas", Soviet-era concrete panel housing blocks that form a significant part of Ukraine's outdated housing stock and face increasing challenges related to physical and infrastructural deterioration (Pleshkanovska & Biriuk, 2021).

But the violence of the winter assault cannot be reduced to just exposure to the weather's brutal cold; how individuals experience extreme temperatures is also dependent on their dwellings, access to heating and cooling technologies, the physiology of their bodies, and even temporal practices such as what times people sleep, how long they have to labor, etc. (Starosielski, 2021). In Lviv, persistent air alarms and rolling blackouts simultaneously compounded the hardships of civilians by disrupting their established rhythms of daily life, illustrating how warfare has shifted beyond military targets to breaching the domestic spaces of the home. The resulting combination of direct explosive impacts and indirect environmental stressors creates a need for methods capable of documenting both physical damage and changes in the thermal and environmental conditions of residential buildings.

This study demonstrates the feasibility of developing a framework to help investigators read ambient conditions as markers of civilian harm through a two-track approach. The first track uses terrestrial laser scanning and thermal imaging to document spatial deformations and anomalous heat-loss patterns in residential buildings affected by kinetic attacks. The second track uses the Analytic Hierarchy Process (AHP) to weight and integrate concurrent ambient datasets – heat loss analysis, air-raid alarms, blackouts, extreme winter conditions – to measure the severity of their effects on civilian life (Saaty, 1980). Doing so offers open-source and visual forensic investigation practitioners a new methodology for quantifying layered environmental harm and the compounding effects of direct and indirect wartime impacts in active conflict zones.

Method and Theory

Track 1: Documenting physical building damage and heat-loss patterns. Fieldwork was conducted in late March 2026 on three representative "Khrushchevka" residential blocks in Lviv, Ukraine. The selection of buildings was based on several criteria: recorded missile/drone explosions near the building with no visible significant damage to the building itself; various "Khrushchevka" facing materials (ceramic tiles and cement plaster).

During the fieldwork laser scanning data (using a terrestrial laser scanner (TLS) Trimble TX6), digital RGB images (using digital camera Sony Alpha IV) and exterior temperature readings (using a Thermal Master Thor002 camera with 512×384 resolution and accuracy of ±2°C) were obtained. The reliability of infrared thermography for building-envelope assessment depends on environmental and measurement conditions, including indoor–outdoor temperature difference, wind, surface emissivity and the timing of image acquisition (Nardi et al., 2018). Inspection was conducted in the early mornings across three consecutive days, where outdoor temperatures ranged from 4.8°C to 7.9°C. Municipal heating was on during this time.

Based on the obtained laser scanning data and digital RGB images, a 3D point cloud and a mesh model were created, which was used to visually identify structural degradation from building deterioration and military shelling. Then, thermal imagery was analyzed to visualize evidence of heat loss across building units.

Track 2: Weighting compounding environmental factors surrounding observed residences. Air-raid alarm notifications (air-alarms.in.ua), electricity outage records (energy-map.info), and weather conditions (ncei.noaa.gov) were analyzed as indicators of wartime disruption. Data was pulled from these sites and filtered to Lviv regions to assess the frequency and durations of these events during the winter months. Saaty's Analytic Hierarchy Process (AHP) was then applied to structure and weight these selected indicators to assess the cumulative severity of ambient stressors across the study area. This approach enables the spatial and temporal characteristics of direct building damage and indirect environmental disruption to be considered within a common analytical framework.

Results

The field survey of three "Khrushchevka" buildings carried out in Lviv produced a set of data that made it possible to assess the damage to the selected objects, using TLS combined with the analysis of RGB images and thermal images.

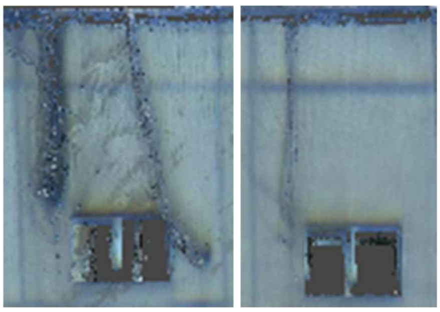

Figure 2. *Cracks on the exterior panel of one "Khrushchevka" visualized on the mesh model*

Figure 3. *Thermal leakage occurring where panels are joined. Warm colors like orange and yellow indicate higher temperatures; cooler colors like blue and purple indicate lower temperatures. Since these readings were captured on the building exterior during winter, higher temperatures suggest where insulation is poor or where heat could be escaping*

Despite the relatively intact state of the selected buildings located in the region of missile or drone explosion, the analysis identified a number of local structural and thermal irregularities characteristic of the buildings. For instance, cracks in the exterior walls as well as rust and corrosion surrounding the seams where the concrete panels are joined are likely caused by damage from nearby attacks or facade structural deterioration. Meanwhile, infrared analysis further reveals these defects are also sources where heat is escaping.

The AHP was then employed to combine the four indicators identified above representing the indirect stress of the wartime environment on the residence of the surveyed buildings. Each indicator was compared against the others using Saaty's 1–9 scale, and their pairwise comparison matrix was used to determine their weights according to the ratio of their individual values. Priorities were ranked based on literature about the stressors' impacts. For instance, power shortages in Lviv restructured domestic and social activities based on the availability of electricity (Błaszczyk, 2025). Meanwhile, children showed symptoms of post-traumatic stress disorder from frequent exposure to air alarm sounds (Yelizarova et al., 2020).

Table 1. *AHP Priorities*

Cat		Priority	Rank	(+)	(-)
1	Heat Loss	22.6%	2	7.3%	7.3%
2	Power outages	51.3%	1	13.8%	13.8%
3	Air alarms	6.8%	4	2.3%	2.3%
4	Extreme weather conditions	19.3%	3	2.2%	2.2%

Table 2. *AHP Decision Matrix*

	1	2	3	4
1	1	0.33	5.00	1.00
2	3.00	1	5.00	3.00
3	0.20	0.20	1	0.33
4	1.00	0.33	3.00	1

Number of comparisons = 6
Consistency Ratio CR = 4.2%
Principal eigen value = 4.115
Eigenvector solution: 5 iterations, delta = 1.4E-8

With CR=0.042<0.10, the derived weighting matrix satisfies the threshold for consistency.

Conclusions

This research illustrates how warfare can turn domestic spaces into hostile environments. The two-track approach enables visible damage and thermal leakage assessments to be paired with open-source data of power outage reports, air alarm notifications, and extreme weather conditions to reconstruct wartime stressors during the peak of Russia's winter assault. By rendering ambient stressors (temperature, sound, and light) visible and measurable, this research demonstrates the technical feasibility to develop methodologies for reading atmospheric conditions as registers of violence.

These results represent a controlled pilot validation across three "Khrushchevka" housing blocks, serving as a proof-of-concept for measuring the severity of cumulative environmental exposure to wartime stressors within civilian neighborhoods. Future work could apply these practices to contrast specific housing stock (such as "Khrushchevkas" versus modern construction), compare experiences based on demographics (how do children or the elderly or different population groups experience these conditions during winter) or incorporate resource-equity metrics (access to fuel, generators, and thermal insulation) to evaluate winterization resilience across communities. By establishing a replicable protocol for quantifying layered physical and ambient stressors, this pilot provides a foundation capable of scaling to other cities throughout Ukraine or cross-referencing with other data (like public death) to measure these stressors' effects on clinical trauma.

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