Using Remote Sensing to Detect Destroyed Urban Landscapes for Their Future Restoration

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Abstract: Urban landscapes are affected by direct human activities across different economic sectors and artificial and anthropogenic disasters. These events significantly alter the typical appearance of cities, including the layout of avenues, streets, public spaces, and industrial areas that are densely packed with infrastructure. Geoinformation technologies and remote sensing methods allow us to understand and assess the consequences of a disaster. This work focuses on using modern technologies to identify damaged and destroyed buildings in Kharkiv city due to hostilities, regardless of their purpose. The synthesis of remote sensing data and open sources allows for more accurate and qualitative detection of building destruction to organize measures for its further restoration. The research describes a methodology for using free high- and medium-resolution remote sensing data in combination with social media and open registers to identify objects of destruction caused by shelling. Based on the results obtained, it can be concluded that additional independent sources must verify the classification of radar data. This will allow us to get a more reliable result.

Keywords: Geoinformation modelling, change detections, geospatial analysis, remote sensing, damaged buildings

1 Introduction

Hostilities continue in the territory of Ukraine, destroying residential areas, including housing, administrative buildings, infrastructure, cultural and architectural construction throughout the country, and especially in the areas of active hostilities. The highly massive nature of the damage and destruction, the continuation of active hostilities in a large part of Ukraine, the constant change of the front line, and the lack of physical access to a large number of settlements complicate the possibility of conducting a detailed, site-specific, comprehensive assessment of damage and destruction. It is difficult and dangerous to inspect damaged and destroyed buildings and constructions using ground-based geospatial data collection methods and UAVs. Therefore, it is advisable to carry out such inspections and monitoring using remote sensing methods and multichannel satellite images of different resolutions. GIS technologies and remote sensing for surveying destroyed urban areas have been actively used in recent studies, as they allow large amounts of geospatial data to be processed, thematic indices to be analyzed, and trends and patterns to be identified (ABDO 2018, AL-MOSAWY et al. 2021, BOLOORANI et al. 2021, FENG et al. 2022, BHASIN et al. 2023, KIM et al. 2023, KUZU et al. 2023, QIAO et al. 2023, STICHER et al. 2023, WANG et al. 2023, TANG et al. 2024, YU et al. 2024). For example, the researchers used Sentinel-1 and Sentinel-2 satellite images for the territory of Kyiv, and geospatial data sets were used as reference models: OpenStreetMap building footprints for buildings and constructions and UNOSAT (The United Nations Satellite Center) for classified destroyed objects (AIMAITI et al. 2022). The UNOSAT data were captured from World-View 3 satellite imageries, and the objects were classified according to

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the European Macroseismic Scale classifier. It should be noted that if damage data is collected using remote sensing, it is initially assigned to the less detailed EMS Copernicus scale. The detailing of EMS-98 degrees occurs in cases where the image parameters make it possible to decipher the image in more detail. The most common European fault classification system is the European Macroseismic Scale 1998 (EMS 98). EMS 98 includes 5 degrees of damage: negligible to slight damage (1), moderate damage (2), substantial to heavy damage (3), hefty damage (4), and destruction (5). It was initially developed to classify damage to buildings caused by seismic activity. Still, in European practice, it is widely used in emergency mapping to classify damage caused by a diverse list of disasters, such as floods, hurricanes, and wars. Studies of the destruction of buildings and constructions have already been conducted in the territory of Ukraine for the Kyiv, Zaporizhzhia, and Donetsk regions based on Sentinel-1 radar data (HUANG et al. 2023, BACHMANN-GIGL & DABIRI 2024, DIETRICH et al. 2024). However, these studies were of a purely technical and scientific nature. The methods proposed in this paper were applied to analyse the situation in Kharkiv city, which is frequently subjected to missile attacks. These attacks lead to the destruction and damage of various buildings and constructions, including historic sites, landscapes, protected areas, and biodiversity. The results of the analysis are further interpreted in this context.

The purpose of this study is to identify destroyed urbanized landscapes using remote sensing data to plan future restoration and development activities. Special emphasis is given to the areas and landscapes that define the city's historical, architectural, industrial, and social uniqueness.

2 Methodology of Researching

The general scheme of the research methodology includes three main stages: collecting initial data and materials, processing geospatial data, and interpreting the research results (Figure 1).

2.1 Data Collection

2.1.1 Radar Data of the Sentinel-1

Sentinel-1 radar data analysis models (VV) were used to identify damaged and destroyed buildings and constructions based on recent studies' experience using remote sensing to monitor destroyed areas. The resolution of the used radar images is 5 meters. It is necessary to use higher-resolution images to obtain more accurate results of the study. Still, these images are commercial, and a sufficient number of images for a particular territory is required to detect changes in objects and analyze time series. During the research, authors found that the destruction of buildings and constructions should be visible on satellite images when there are significant changes in the shape of the roof or height. If there is a fire without destruction, then changes in buildings and constructions will be virtually invisible on radar images. Instead, the situation is the opposite of multispectral imagery, so authors additionally used Sentinel-2A imagery. Sentinel-1 satellites provide data updates every 6 days. The study used archived radar images of this satellite, which are publicly available. The authors determined the dates of the images by taking into account the high activity of military operations in the territory of Kharkiv, namely massive rocket and artillery attacks, UAV, and multiple launch rocket system (MLRS) attacks.

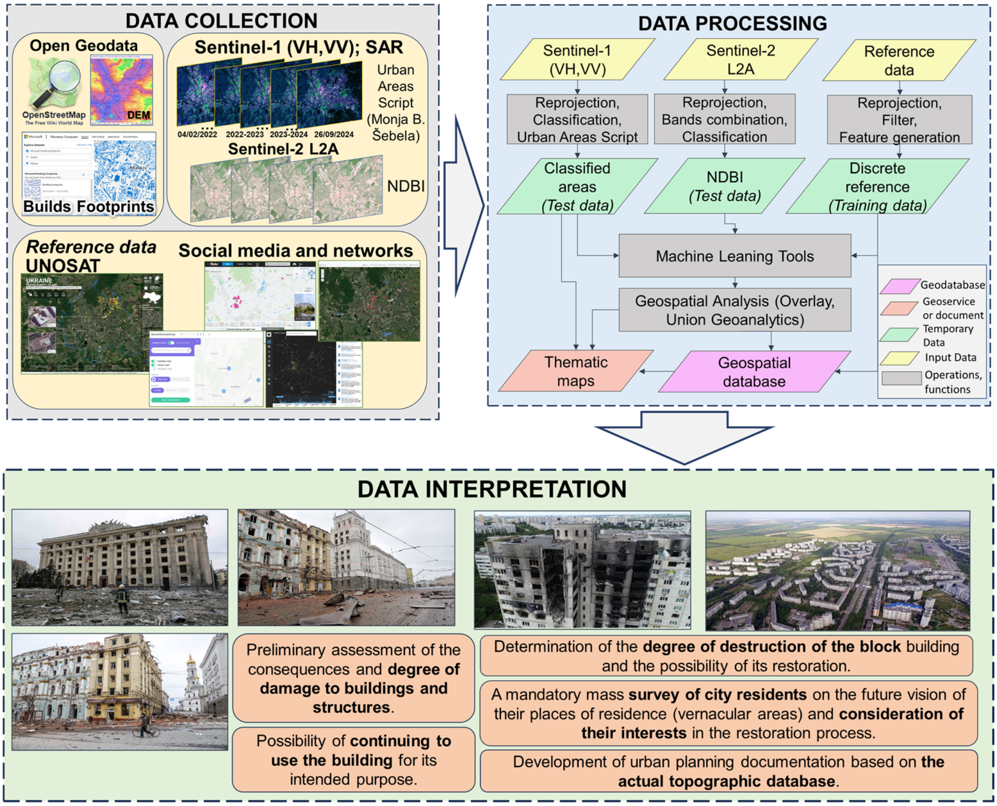

Fig. 1: The methodology schema of the study on destroyed urbanized landscapes using remote sensing data and open geospatial data. (Performed by the authors)

Based on these events, the following dates were determined: 2022/21/02, 2022/04/10, 2022/04/22, 2022/28/05, 2022/03/07, 2023/16/02, 2024/30/01, 2024/30/03, 2024/29/05, 2024/26/09, 2024/01/11.

2.1.2 Multispectral Satellite Images Sentinel-2A

Sentinel-2A satellite images of the L2A processing level defined the Normalized Difference Built-up Index (NDBI), which narrowed the study's boundaries to the built-up area of Kharkiv city, which was directly investigated in this paper.

2.1.3 Social Media Data

Also, data from social networks, official media, and published reports from executive and investigative bodies were used to verify the destruction or damage to buildings and constructions, which only improved the quality of the results of image classifications and ruins identification.

Image location data is stored within the context of the post rather than being attached to the image itself. Some social networks can clean up Exif data so that you can get any data from a social network only by post ID. You can get the location value only by posting the ID and requesting it on Instagram. That is, you cannot take a random picture of destruction and get information about it. When there is a post or an array of posts where this picture and the destruction occur, you can get the location by making an API request to Instagram using the post ID and get the location data. One of the main disadvantages of such geodata is that the location specified by the user for the image does not correspond to reality. Therefore, it is always necessary to check this location if the accuracy of the research result is high. There is also Google Lens. It is a picture search service that analyses similar images. If an exact match is found, you can follow the link and reconsider the location.

2.1.4 Reference Values

Two data sets were utilized to evaluate the accuracy and reliability of the research findings: Microsoft's geospatial data on the footprints of buildings and constructions and a geospatial dataset concerning the destruction and restoration of buildings and constructions in Ukraine (MICROSOFT 2023). A set of damaged and destroyed buildings and constructions is available via the API service: https://reukraine.shtab.net/api/v1/building/ (Figure 2).

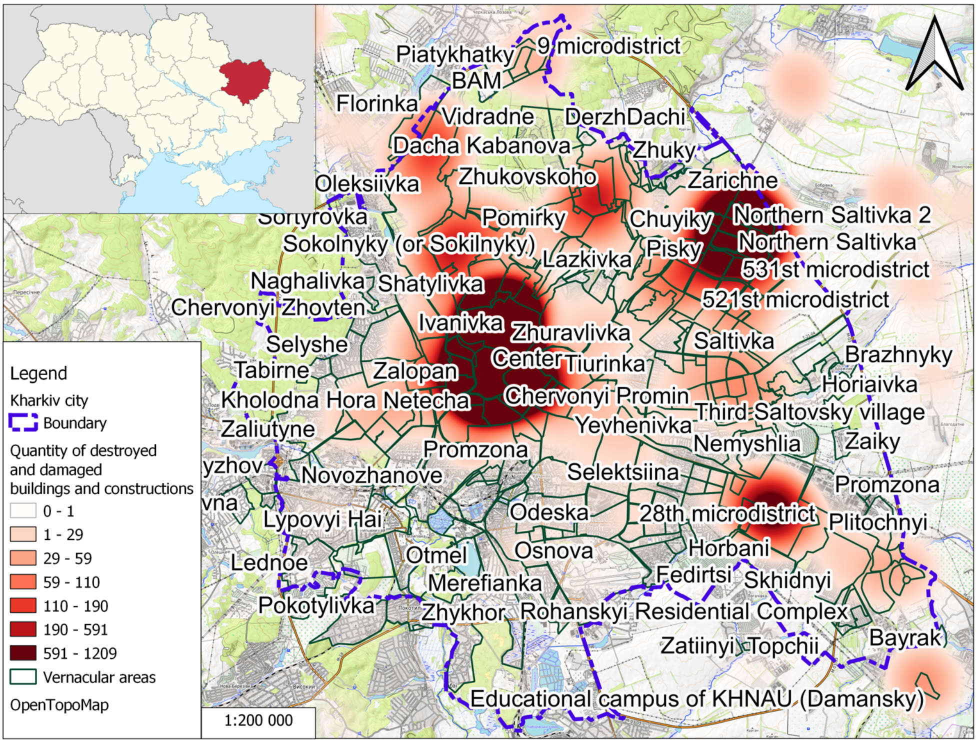

Fig. 2: Heat map of the spatial distribution of destruction in the city of Kharkiv for 2022-2024 (according to the project «The Map of Recovery»). (Performed by the authors)

The information about the objects and their locations has been recorded in the platform's database, using data provided by volunteer and public organizations, as well as local governments. This information has been approved by the General Staff of the Armed Forces of Ukraine, which confirms the safety of the project (ANTI-CORRUPTION HEADQUARTERS 2025). This study used the following information about the object in this database: location, address, date of destruction, photos before the destruction, photos of the destruction and the process of restoration and its completion, and a link to the source of information about the event. Currently, this platform is supported by crowdsourcing technology. Through this service, we have obtained the relevant geospatial data in JSON format for use in QGIS.

2.2 Data Processing

The Sentinel-1 radar images were processed using SNAP software. This included using orbit files, calibration, filtering of speckles using the Lee method, terrain correction, and linear conversions to and from decibels (dB). During the study, Thermal Noise Removal and the Remove-GRD-Border-Noise processes were also applied.

Furthermore, the Semi-Automatic Classification Plugin, a machine learning tool, was utilized to classify Sentinel-2A multispectral images from March 2022 in the visible spectrum within QGIS (Figure 3). This classification aimed to obtain the outlines of buildings and constructions. Following this, the processed radar data were filtered to exclude any sections that overlapped with, crossed, or were contained within the resulting contours of the classified buildings and constructions. This study used geospatial data captured through the Flickr API service, which provides free access to photo geospatial data, including EXIF files. After processing the received data in *.csv format, we created files in *.json format for use in the QGIS environment. The authors verified the classified radar images by performing an overlay analysis of the above geospatial datasets in QGIS. By processing open data from the registers, 1039 destruction records were obtained (yellow color in Figure 4).

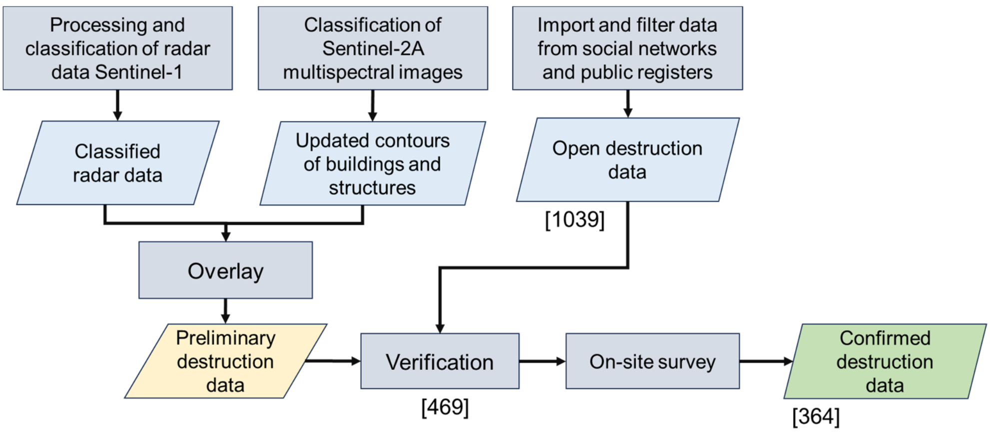

Fig. 3: Scheme for processing and analyzing data on the destruction of buildings and structures. The quantity of objects obtained is indicated in square brackets. (Performed by the authors)

This data was then compared with the classified radar images, and 469 identified objects were obtained. Five hundred seventy objects had damage that was not captured by the radar images (building facades, windows, doors), as higher-resolution images were required to identify them. After the on-site survey, the results were updated: 364 damaged objects with 4-5 degrees of EMS (red color in Figure 4). 105 objects had surface changes caused by reconstruction and restoration.

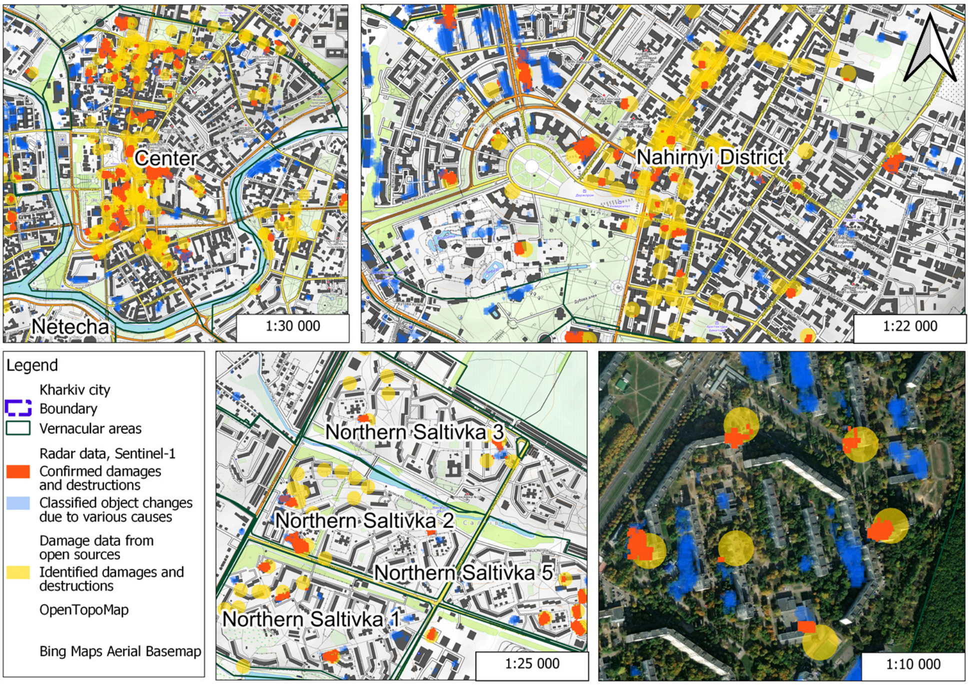

Fig. 4: This is a map of classified destruction based on radar data and verified data, using open data and local experts' help in Kharkiv City, in November 2024. (Performed by the authors)

Other classified radar data (shown in blue color in Figure 4) were not confirmed, theoretically indicating other surface changes, such as those resulting from reconstruction, restoration, renovation, and various construction activities. Since it is practically impossible to record damage to the facade, windows, decoration, and other elements of buildings and constructions on radar data with a resolution of 5 meters or more, following the EMS Copernicus scale, this study recorded damage of 4-5 degrees. For 1-3 degrees, it is advisable to use high and very-high-resolution images.

3 Results

This paper published a test set of geospatial data for a specific area of the city to reproduce the study and use the proposed method: https://doi.org/10.5281/zenodo.14622373.

It was found in the previous study that the population shapes the urban environment, so this paper focuses on residential and historical buildings and performs a geospatial analysis taking into account the established vernacular areas of Kharkiv city (KARPINSKYI et al. 2024). This paper investigated the established vernacular areas of the city of Kharkiv and analyzed their historical urbanized landscapes to determine their damage and subsequent restoration. It is essential to understand that vernacular areas demonstrate the direct residence of people in the city and the centers or hubs with which they associate themselves (Figure 5).

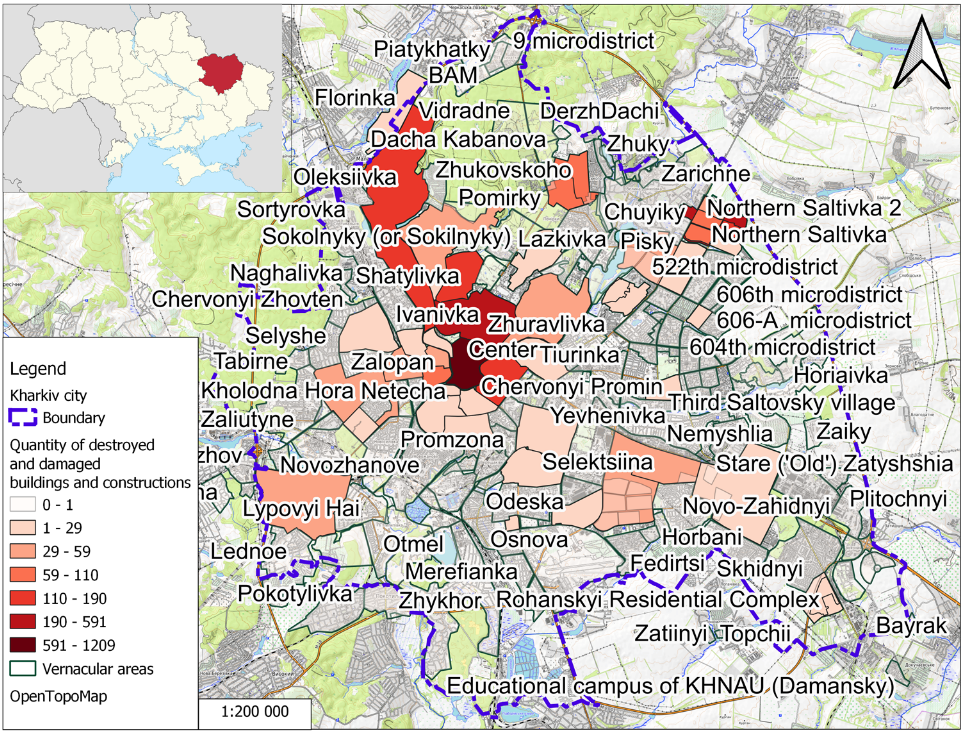

Fig. 5: Map of the spatial distribution of the intensity of destruction in Kharkiv city by vernacular areas as of November 2024. (Performed by the authors)

The thematic map illustrates that the most affected vernacular areas of Kharkiv include Nahirnyi, Center, Oleksiivka, KhTZ (Kharkiv Tractor Plant), Promzona, Northern Saltivka, and various neighborhoods in Saltivka. The highest concentration of damage is found in the city center, where most administrative and historical buildings are located. Furthermore, many institutions and local government offices are housed in historic buildings and architectural monuments. Thus, the destruction of these sites carries significant implications: it not only destroys the historical value of the city but also eliminates key decision-making locations. Historically, the suburban area of Kharkiv has been primarily residential, especially in the northeast, where there was extensive fighting. This fighting led to significant damage and destruction of residential buildings in those areas. The interpretation of the results obtained, namely the models of the identified destroyed urbanized landscapes, allowed us to formulate the following recommendations for planning and organizing measures to restore these landscapes:

- Preliminary assessment of the consequences and degree of damage to buildings and constructions.
- Identify signs of the possibility of continuing to use the building for its intended purpose.
- Determine the degree of destruction of the block building and the possibility of its restoration.
- Planning and organization of short-term and long-term measures for rehabilitating housing stock, infrastructure facilities, and public areas.
- A mandatory crowdsourcing of city residents on the future vision of their places of residence (vernacular areas) and consideration of their interests in the restoration process.
- Development of urban planning documentation based on the current topographical basis.

The developed GIS project for maintaining a thematic dataset of destruction objects caused by hostilities allows data to be displayed, edited, and analyzed at the operational level in the QGIS environment (KARPINSKYI et al. 2021). Geoinformation modelling of the destruction objects in Kharkiv was used to analyze the affected areas. The data obtained as a result of geospatial analysis can be used for more effective management decision-making.

4 Discussion

The following limitations were identified in this study, which directly influenced the results:

1. We utilized freely available Sentinel radar and medium-resolution multispectral images. Higher-resolution data would have enabled a more precise assessment of all damage levels and provided detailed outlines of damaged and destroyed buildings and constructions.

2. The analysis was based on radar data from only one satellite rather than combining data from two or more satellites, which would have improved the reliability of the results.

3. The radar data for the city of Kharkiv captured changes in the height and/or roofs of buildings. These changes could be attributed not only to missile or artillery attacks but also to reconstruction, restoration, and other construction activities in the studied areas.

Furthermore, it is crucial to study the spatial planning of the damaged or destroyed vernacular areas of the city. This research should consider the establishment of new or existing administrative, entertainment, educational, industrial, and other centers while taking into account the city's infrastructure and the needs of residents, the state, and businesses.

5 Conclusion and Outlook

As of November 2024, a total of 49 vernacular areas in Kharkiv and 364 buildings and constructions (with 4-5 EMS degrees) were affected. The proposed method for detecting changes using radar data and open-source information is effective for quickly analyzing damage and destruction to settlements, communities, districts, regions, and any other large areas, even in conditions of limited resources. This approach allows for the assessment of the extent of damage and losses in a relatively short timeframe. Additionally, it provides the initial data necessary for calculating the cost of damaged real estate and the expenses associated with restoration efforts. The proposed method is recommended for use in areas affected by anthropogenic or natural disasters. It should be noted that it is advisable to examine not only large cities but also towns and villages, especially the state of critical infrastructure, without which recovery will be virtually impossible.

The next stage of the research will be to determine the specifics of analyzing damaged areas caused by hostilities and natural disasters, identifying common threads and differences.

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