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Network of Resources (NoR) Initiative
Sponsorship Report

Urban Transformation Project Sarajevo (UTPS)

Introduction

Sarajevo, the capital of Bosnia and Herzegovina, is a city steeped in history and cultural diversity. Located within the Miljacka River valley and surrounded by the Dinaric Alps, Sarajevo's urban fabric is a unique blend of different influences, reflecting its complex past.

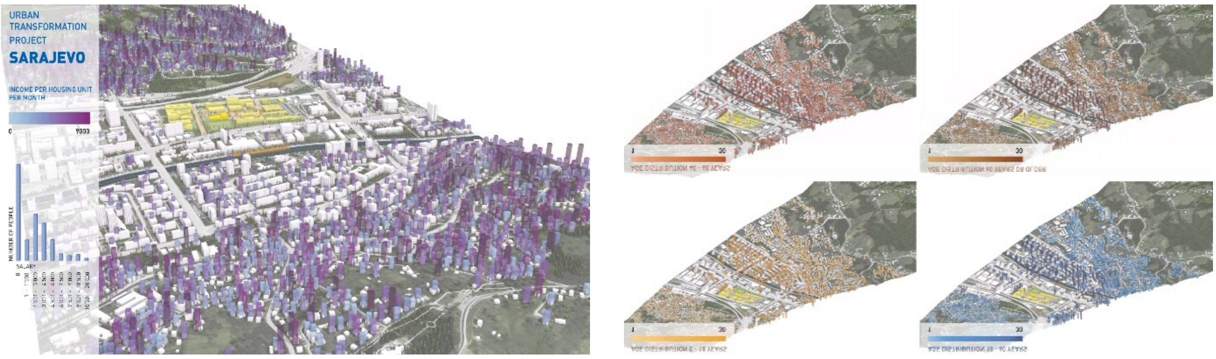
Historically, Sarajevo emerged as a significant trade and cultural center during the Ottoman Empire in the 15th coexist in proximity, symbolizing the city's multicultural identity. The late 19th and early 20th centuries added a European flair to the city's landscape, evident in its grand public buildings and wide boulevards. However, Sarajevo's modern history is marked by the tragic events of the 1990s, including the Bosnian War, which profoundly impacted its urban development and social fabric. Today, Sarajevo is a vibrant city that honors its past while looking toward the future, characterized by a resilient spirit and a commitment to rebuilding and reconciliation.

Sarajevo is one of the most polluted city in Europe in the winter months. Nestled in a valley surrounded by mountains, the city experiences temperature inversions, especially during winter, which trap pollutants close to the ground. A major source of pollution is the widespread use of coal and wood for heating, as many households rely on these fuels, releasing significant amounts of particulate matter and harmful gases into the air. The city's aging vehicle fleet and traffic congestion add to the problem, as older cars emit higher levels of nitrogen oxides and fine particulates. Industrial facilities, often using outdated technologies, further contribute to pollution, while urbanization and construction generate dust and reduce the city's green spaces, limiting nature's ability to filter the air. These issues are compounded by Sarajevo's cold winters, which increase heating demand and worsen air stagnation, leading to unhealthy pollution levels. There is a need for sustainable development practices to address these issues.

Sarajevo (fig 1, 2)

The UTPS (Urban Transformation Project Sarajevo) aims to develop a comprehensive 4D georeferenced digital twin of the City of Sarajevo. It provides a multidimensional understanding of the city, its topography, vegetation, population, settlements, infrastructure and mobility in order to address the challenges the city is facing. It helps visualising patterns and trends that may not be apparent through the first sight as they might only become visible, when different data are brought into a context with each other. The digital twin as a virtual representation of a physical entity is also an important tool for communication. By visualizing complex urban dynamics in a model, all the stakeholders (citizens, politicians, urban planners, Investors, Foundations etc.) are enabled to better grasp the interrelationships between the factors that have an impact on the city and its future. This creates a foundation for interdisciplinary dialogue, bringing together diverse interest groups and fostering collaboration.

Our area of interest lies in the central part of Sarajevo, specifically within the district of Marijin Dvor. This location is highly accessible and strategically positioned near significant urban amenities, including the University of Sarajevo and various public transportation options. The university campus is currently undergoing development, with the Chair of Professor Klumpner at ETH Zurich planning a small-scale intervention. The interventions are being discussed in collaboration with local authorities, leveraging modern tools such as a digital twin to visualize proposals and establish a robust foundation for informed decision-making.



Screenshot of the digital twin visualizing population data

However, the creation of a digital twin for this region has presented unique challenges due to the limited availability and accessibility of Geographic Information System (GIS) data. The data provided by local authorities included only the building footprints and their corresponding heights, enabling the generation of rudimentary volumetric models. This resulted in an abstract representation of the urban landscape with a low level of detail and simplified flat-roof structures.

To develop a more accurate and detailed digital twin that reflects the actual built environment, including roof shapes, an innovative approach was required. Incorporating roof shapes into the model is critical, as it allows for more precise assessments of solar potential. Such evaluations are important for exploring sustainable energy solutions, particularly in informal settlements where solar energy could replace coal and wood as primary heating sources, significantly mitigating pollution.

The initiative of the Network of Resources (NoR), supported by the European Space Agency (ESA), played a pivotal role in addressing these challenges by providing credits to access valuable datasets from UP42. This report details the methodology and technical processes employed to extract three-dimensional building models and their corresponding roof geometries from raster imagery. The foundational data, including the Digital Surface Model (DSM) and Digital Terrain Model (DTM), were processed using photogrammetric techniques. The resulting 3D models offer a higher level of detail and accuracy, providing a powerful tool for urban planning and sustainability initiatives in Sarajevo.

Methodology

The utilization of raster imagery to detect objects and derive GIS data is a critical technique for addressing the scarcity of spatial information in some urban areas. The base raster data, comprising the DSM and DTM, were purchased from the UP42 platform using credits provided by the Initiative Network of Resources, supported by the European Space Agency. UP42 is a platform that consolidates datasets from various providers, enabling users to purchase, process, and store them in the cloud or to download them to process the images further.

The DSM includes elevation data for both the terrain and built structures. It is provided by Vexcel Aerial at a high resolution of 0.07 meters per pixel. Satellite-based data, primarily from the WorldView series of satellites operated by Maxar Technologies, are used to generate the Digital Surface Models (DSM) of Vexcel Aerial.

The DTM, representing the bare earth surface without vegetation and buildings, was sourced from Intermap's NEXTMap. It is derived from airborne radar data, collected using Intermap's own radar systems, such as the

Interferometric Synthetic Aperture Radar (InSAR). These systems are deployed on aircraft to gather detailed elevation information over large areas.

To create a detailed 3D representation of urban structures from photogrammetry, high-resolution elevation data and georeferenced building footprints were required. In areas where such data is unavailable, building footprints can be generated from satellite imagery through artificial intelligence analysis. Although building footprint data provided by local authorities were available, these datasets did not always align perfectly with the underlying raster images, requiring additional adjustments to ensure compatibility. UP42 offers a cloud processing tool that was utilized to attempt generating these footprints, aiming for accuracy and compatibility with the raster images. However, the results were imprecise because the algorithm was not sufficiently trained for buildings resembling the structures in Sarajevo. Producing clean and reliable shapes would have required extensive post-processing, making this approach inefficient.

Given that we already had footprint data available, we opted to utilize this information and adapt it to the raster For the subsequent steps, we used the desktop application ArcGIS Pro by ESRI to continue the workflow.

The Up42 Plugin for ArcGIS Pro facilitates seamless integration between the Up42 platform and ArcGIS Pro, allowing users to load geospatial data directly into their GIS environment for further analysis and visualization.

The following chapter presents the results of refining the building footprints through deep learning based segmentation. Furthermore it outlines how each segmented component was transformed into a 3D polygon, with specific attributes for height and roof form.

The outcome of this methodology is a comprehensive dataset of 3D building models with detailed roof shapes, accurately representing the urban environment. The models were visualized in ArcGIS Pro, allowing for further analysis and integration into urban planning frameworks.

Results

Ideally, both raster images (DSM and DTM) should be of the same resolution. However, since the highest resolution available for the DTM was 5.56 meters, we used the best data available. This dual dataset is essential for accurately modeling 3D structures through photogrammetry. The images were cropped to identical extents to ensure spatial alignment. To maintain compatibility, both datasets were resampled to have the same pixel size of 0.1m and were adjusted to have matching numbers of columns and rows.

The ArcGIS Pro scene, the feature layer containing the building footprints, and the associated raster images must have the same coordinate systems too. Specifically, for the area of Sarajevo, the geographic coordinate system should be set to WGS 1984, the projected coordinate system to WGS 1984 UTM Zone 32N, and the vertical coordinate system to EGM96 Geoid.

The attention to align the datasets with each other is critical at this stage, as even minor discrepancies in spatial references, pixel sizes, pixel types or extents can propagate errors through subsequent processes.

The next step involved creating a normalized Digital Surface Model (nDSM) using the raster functions available in the Image Analyst extension. A nDSM is derived by subtracting the DTM from the DSM. This operation produces an elevation raster that not only reflects the ground-level elevations of features but also captures their relative heights. To enhance the interpretability of the nDSM, the symbology was adjusted by applying a color range set to "Elevation01." Additionally, the stretch type was configured to "Histogram Equalize." This setting optimized the display of elevation differences by redistributing pixel values for clearer visualization in the scene. Before running the nDSM calculation, it was critical to ensure the correct pixel output type was set. This parameter determines the range and precision of the values that the raster can store. For this analysis, a 32-bit floating-point format was chosen to preserve decimal precision in the resulting raster, which is particularly important for accurate elevation data representation

To further refine the accuracy of our model, particularly for buildings with a greater footprint and multiple compartments or sections that vary in height, we took the decision to segment the building footprints into smaller, more precise components. This segmentation enabled us to assign distinct elevations and roof shapes to each individual section. By breaking the footprints into smaller parts, we were able to create a more accurate and realistic representation of the buildings. It's not only improving the quality of the digital model and its ability to reflect the true complexity of the urban environment, but these details are also particularly important for accurately modeling shadow patterns, which have an impact on the outcome when we are calculating solar potential in the subsequent steps.

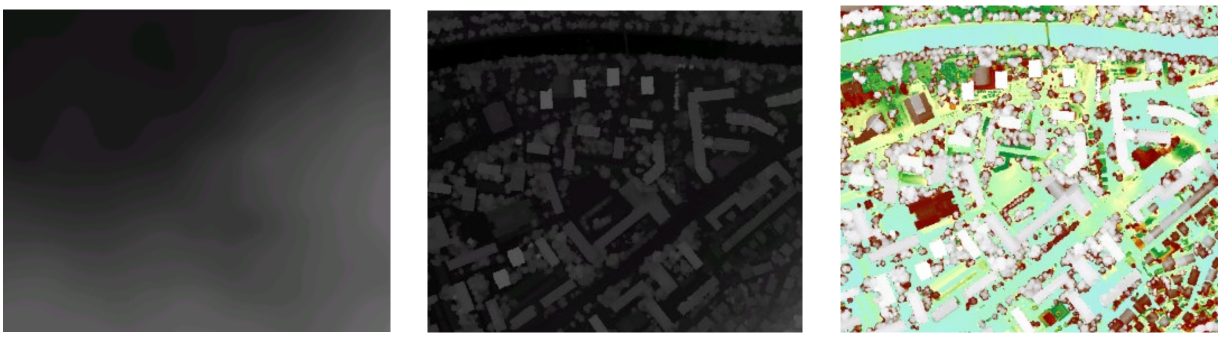
The segmentation of building footprints was accomplished through deep learning techniques. We trained the model by labelling the distinct compartments of the building footprints based on spatial attributes and height variations of the raster image below. The model learned to correlate the features of the raster data with the segmented compartments of the building footprints. Once the model has been trained, it was validated using a separate set of labeled data that was not included in the training phase. This ensured that the model could be applied to new building footprints and accurately segment them into individual parts, saving time through automated workflows.

The resulting data often requires refinement to address inaccuracies and imperfections. This refinement process began with an assessment of the output to identify misclassified segments, overlapping polygons, gaps in building footprints, or artifacts caused by noise in the raster data. To clean and improve the segmentation, the polygons were first simplified and smoothed to reduce irregularities along their boundaries, ensuring that they better align with the natural shapes of the buildings. For this reason the *regularize building footprint* tool of the 3D Analyst in ArcGIS Pro was used. Once the data has been cleaned and validated, it was ready for integration into further steps of the process.

Left: Buildings with lower level of detail; Right: Segmented buildings with higher level of detail

The subsequent steps involve assigning each segment an appropriate height and roof form, ensuring accuracy and a higher level of detail throughout the model.

Before creating 3D shapes out of the segmented footprints, it was important to verify that the feature class supported Z-values, as this enables the representation of characteristics in the Z-axis such as height. To ensure compatibility, the features were copied into a new feature class where Z-values were enabled



From left to right: DTM, DSM, nDSM

ArcGIS Solutions offers a variety of preconfigured tasks within ArcGIS Pro to streamline and standardize common GIS workflows. These tasks are designed to guide users through specific processes, enhancing efficiency and ensuring best practices. One task is the "Create buildings" task within the *3D Buildings* solution. This task facilitated the generation of our 3D building layer. It can be downloaded directly from ArcGIS Online and deployed into the model. Before the task can be run, the prepared DSM, DTM, nDSM and segmented building footprints were selected. The roof types were generated based on predefined geometric criteria, such as minimum flat roof area, minimum slope roof area and minimum roof height. In our case we used the default settings. After the task run a few minutes, a new feature class was generated containing polygons with the roof information. Yet no 3D buildings are visible.

The next step was to apply 3D symbology to the output buildings layer. Therefore we navigated to the symbology pane and set the fill to procedural fill. A procedural fill in ArcGIS Pro is a symbology option used to visualize 3D objects in a scene. It applies procedural rules to features, allowing them to be rendered dynamically on their attributes. The procedural fills rely on rule packages, which are files containing modeling rules created in CityEngine or ArcGIS Pro. These packages define the appearance and behavior how 2D features are represented in 3D. They specify how geometry is created and which materials or textures are applied. The rule package used in the model (*LOD2BuildingShells_Meters.rpk*) was provided by ArcGIS Solutions. Under Display Options the façade and the roof colors can be changed if desired. Level of detail (LOD) refers to the geometric intricacy of 3D models. Based on the input data, buildings with a level of detail 2 (LOD2) will be created which refers to a 3D polygon with roof shapes but without details pertaining to the facade of the structure such as windows, doors, and so on.

After the 3D buildings were created the model, we started to revise the output again, identifying and correcting irregularities, such as unusual heights assigned to specific segmented parts.


Left: Buildings without roof information, provided by the local authorities; Right: 3D generated buildings with specific roof shapes

The digital twin represents an intermediate step in our project to improve Sarajevo's urban environment. The generated roof shapes provide critical data for assessing the solar potential of hillside settlements. In the next phases, opportunities will be identified to harness solar energy as a sustainable alternative to traditional heating systems, such as burning coal or wood as mentioned in the beginning. Transitioning to solar energy will significantly reduce emissions, contributing to better air quality and a healthier living environment for Sarajevo's residents. This approach aligns with our broader goals of sustainable urban development and environmental enhancement.

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Sources

ArcGIS Solutions «3D Buildings»

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UP42

https://up42.com/marketplace

https://console.up42.com/data-management/map?center=0%2C0&z=2&bbox=74.67352%2C-74.67352%2C-74.67352%2C74.67352

Images

Figure 1, 2 https://meetbosnia.com/what-to-see-in-sarajevo-amazing-local-guide/

Film

https://www.youtube.com/watch?v=r84BamC46fo

Article about the urban transformation project Sarajevo:

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