# Interactive Web-based 3D Solar Shadow Map

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**Abstract.** Urban areas are characterized by a complex topography of buildings, terrain, vegetation and temporary structures, which, depending on their extent, geometry, geographic location and daytime, cast shadow on their surroundings. Given the importance of sunlight for various groups of interest and tasks, we argue that a comprehensive, accessible, and intuitive way of predicting its availability is surprisingly lacking. In our research, we investigate how to enable the visual communication of urban solar conditions for various real-world usage scenarios like finding a sunny spot in the vicinity, parking a solar car in the sun, or taking a photograph of a particular building in a favorable light. Furthermore, since such activities span over time, a visualization of shadow motion is desired. A web-based prototype is being created in order to evaluate technical feasibility as well as user acceptance.

**Keywords.** Interactive map, 3D, Realtime, Sun, Shadow, LBS, WebGL, CityGML, Three.js, Shader, Open Data, Smart cities, Exploration

## 1. Introduction

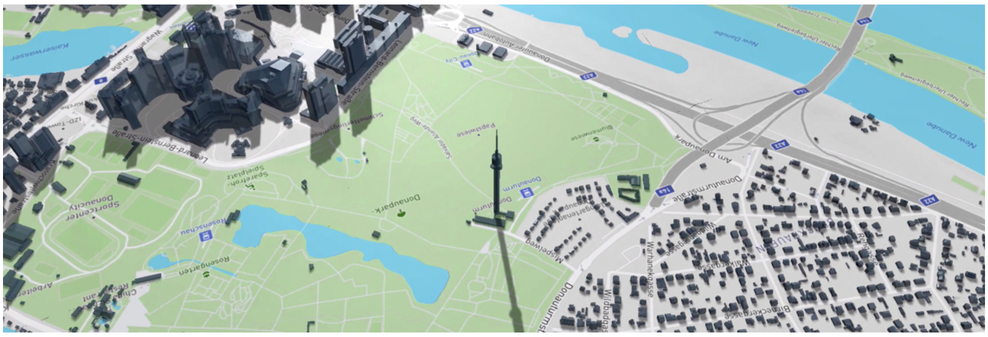

**Figure 1.** Actual footage of the 3D interactive web-based solar shadow map. This shows Vienna on September 25th at 13:50 with precise sun position, rendered at 60 fps in the browser. (© Basemap: Mapbox & OSM Contr., 3D buildings: CC BY 4.0 Stadt Wien – data.wien.gv.at)

LBS 2019
15th Conference on Location Based Services
Vienna, 11–13 November 2019

Published in "Adjunct Proceedings of the 15th International Conference on Location Based Services (LBS 2019)", edited by Georg Gartner and Haosheng Huang, LBS 2019, 11–13 November 2019, Vienna, Austria.

This contribution underwent double-blind peer review based on the paper.
https://doi.org/10.34726/lbs2019.62 

The Sun is a prerequisite for life on Earth. It impacts overall temperature, plants' growth rates and photovoltaic energy production, up to health and mental conditions in humans (Mead 2012). By building an interactive, browser-accessible map, based on open 3D data (terrain, buildings and vegetation), we want to make humans understand sun/shadow conditions and allow them to plan and act accordingly. For any time, at any location, from any perspective. To allow required temporal and spatial freedom that enables interactive exploration of solar shadows within a 3D environment, a client-side approach is obvious.

In order to minimize entry- and compatibility-barriers (i.e., we want to cover modern location-aware mobile devices, as well as classic desktop computers) while at the same time maximizing accessibility (i.e., no installation, instant access, streamed data), we decided to build upon web-technologies. This strategy, however, given the vast amount of data and the aim to achieve interactive frame rates in contrast to browsers' reduced access to GPU power and memory, creates a potential performance bottleneck.

## 2. Method

Initially, available tools were researched in regards for their adaptability or extensibility. *Cesium*, *Mapzen*, *OSM Buildings* and *ArcGIS*[1] were evaluated and eventually considered impractical for the task: They were either too bloated, not "real" 3D (i.e., "2.5D") or closed source and therefore not editable and extensible. We therefore decided to initiate an implementation from scratch, based on the lightweight high performance Javascript WebGL based 3D engine *Three.js*[2] – capable of producing real time (60 fps) visualizations as depicted in *Figure 1*.

### 2.1. Data

The geometries required for accurately calculating the lighting situation in an urban environment need to be combined from different data sources, in different formats, often in different coordinate reference systems. This in turn requires a powerful and scalable pipeline to incorporate all relevant aspects to render solar shadows, with the eventual aim of creating a flexible system that will be working globally and for any city that provides 3D models of its buildings and other potentially relevant layers of information.

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[1] https://cesiumjs.org, https://www.mapzen.com, https://osmbuildings.org, https://developers.arcgis.com

[2] https://threejs.org

Starting out with worldwide terrain data as well as building and vegetation data of Vienna, any occluding structure should eventually be added to the system. Gröger & Plümer (2012) define different levels of detail (LoD) for 3D building models, whereas LoD1 represents blocks without roof structure while LoD2 also contains the latter. LoD3 enhances this by integrating “architectural models with detailed wall and roof structures, balconies, bays and projections” (Gröger & Plümer 2012).

Biljecki et al. (2017) discuss the qualitative impact of LoD on shadows. His conclusion, however, is based on a procedurally created city model. The city of Vienna provides an LoD2 model which we are currently using as Vienna has many pointy roofs: An abstraction as extruded blocks would intuitively lose significant detail. We plan, however, to integrate LoD1 in Vienna as well and research differences in the shadow visualizations between the two levels – based on a real-world scenario.

New York and Berlin offer data of similar quality and are to be added next. Other occluders, including clouds and atmospheric conditions might be added in a later stage, according to available data.

## 2.2. Map

A web-based interactive map is currently being built that combines 3D terrain data, 3D building data, tree cadasters and a basemap. The map prototype is draggable and zoomable, dynamically loading required resources, covering the whole earth. Its basemap and terrain are streamed from tile-servers. Terrain elevation is based on RGB-encoded height. A GPU vertex shader displaces 3D-planes accordingly. After this process, the terrain is also able to cast and receive shadows, further contributing to an encompassing and realistic rendering. Performance is convincing and fast enough to render a significant part of Vienna in realtime on a 2016 MacBook Pro as shown in *Figure 2*. The map will be freely available on https://shadowmap.org – which will also be the starting point for further user testing.

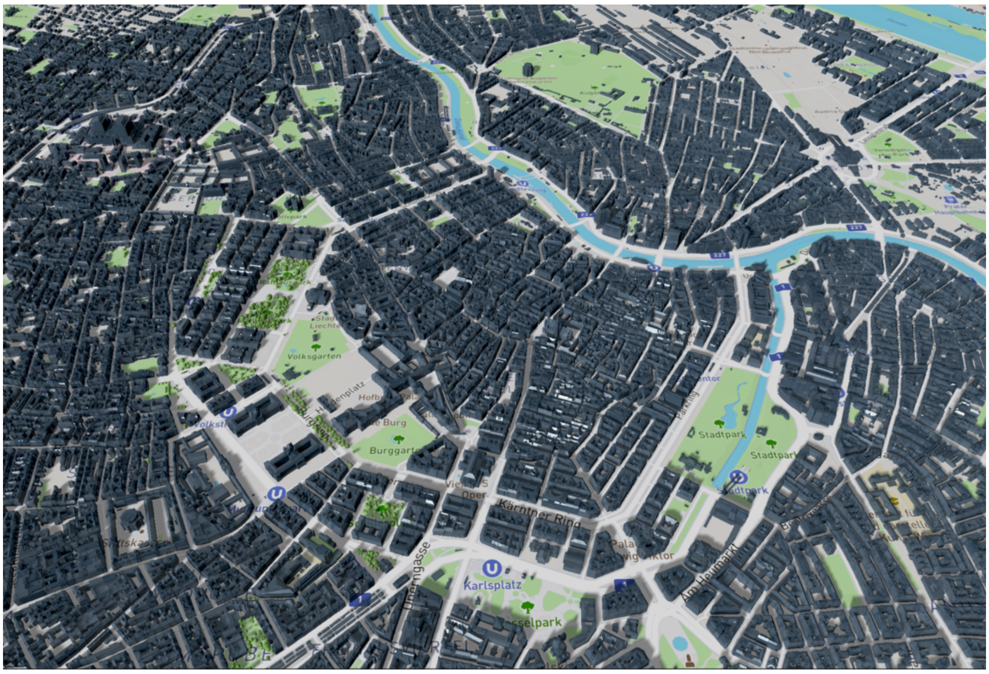


**Figure 2.** Shadow simulation of Vienna's central districts. Due to its 3+1 dimensional nature, zoom, perspective and time can be defined by the user without any constraint. Hereby, users are able to even investigate shadow situations on building facades at sunrise or sunset – a scenario that can't be covered by 2D server-generated imagery. (© Basemap: Mapbox & OSM Contributors, 3D buildings: CC BY 4.0 Stadt Wien – data.wien.gv.at)

## 2.3. Location based services

By employing the current location, one is able to immediately grasp the shadow situation in nearby surroundings. A person with just a few minutes of spare time can effortlessly find the closest spot to enjoy their lunch break in the sun. The driver of a solar car could request sunny parking spots within the next 3 blocks.

Thinking ahead, even routing could be tuned based on a sun/shadow-scenario: A person walking a longer distance through the city during a hot midsummer evening would most probably prefer a route through a shady neighborhood. Vice versa the route for a solar car. Comparable scenarios are considered for further investigation.

## 2.4. Time integration, shadow accumulation

Most human activities take place over a period of time, not in a temporal instant, causing solar shadows to move. Miranda et al. (2018) argue the importance of shadow simulation in urban design and introduce efficient algorithms to render time-integrated shadows that span an arbitrary timeframe.

While maintaining high quality visualizations, their application, however, is limited to offline usage and targeted towards professionals like city planners and architects.

In our solution, the factor of moving shadows is incorporated by integrating the sun's motion that covers arbitrary timeframes within a given day, as shown in *Figure 3*. Shadows are accumulated by projecting shadows from astronomically precise sun positions (Agafonkin 2009) spanning the desired timeframe. For every sampling point, a shadow is rendered using *shadow mapping* (Williams 1978) – in our case a filtered, thereby higher quality version of it (Fernando 2005). In contrast to *polygonal shadow volumes*, *shadow mapping* also works for curved occluders on curved surfaces which is a fundamental requirement in our endeavor since we utilize non-planar terrain. The accumulated shadow visualization is generated by multiplying the light intensity by $1/N$ ($N$ = number of sampling points) while simultaneously rendering all hereby created shadow maps. $N$ directly affects quality and speed of the rendering. *Figure 3* uses five sampling points. We plan to enhance real-time performance by "baking" those generated shadow maps into the scene and introducing constraints on time and perspective to compensate.

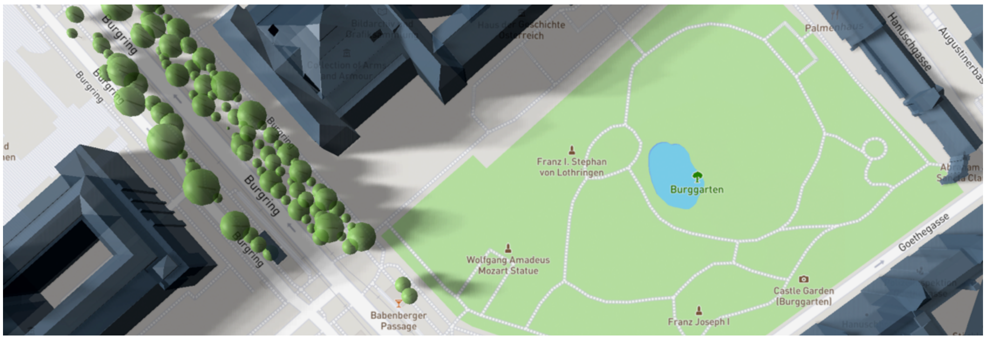


**Figure 3.** Burggarten, a well-known park in the center of Vienna, late afternoon of September 14th, 2019. Accumulated shadows over the period of one hour. 3D buildings based on LoD 2 DXF models. Trees based on Vienna's open data tree catastre. (© Basemap: Mapbox & OSM Contributors, 3D buildings: CC BY 4.0 Stadt Wien – data.wien.gv.at)

## 3. Findings

Vienna provides a CityGML and DXF (LoD2) dataset of buildings via its open data initiative. By conversion and lossy 3D model compression, the file size of the metadata pruned model could be brought down from 1.42 GB to 47 MB without sacrificing image and data quality. Vienna's tree cadaster on the other hand is a massive single >100 MB JSON file, covering metadata and location of 199.826 trees, requiring prior processing and tiling to become computable. While these optimizations are desirable in general, they become crucial in a web-context: The often redundant, heterogenous data sources need to be compressed and minimized in order to reduce loading times and also integrated in a way performant enough to allow 3D real time web-based visualization.

## 4. Conclusion

To realize an interactive 3D web-based solar shadow map, various technical hurdles need to be overcome. The combination of 3D buildings, 3D terrain and vegetation with the aim to reach worldwide coverage – supporting arbitrary points in time and in space – is challenging. Even more in a web environment and the aim to be mobile ready. However, at the current state of our prototype, we are on our way to prove feasibility. Next step will be the finalization of the UI as well as the deployment of our prototype on shadowmap.org followed by user experience testing and feedback evaluation.

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