Human Factors in Design, Engineering, and Computing, Vol. 238, 2026, 662–673
https://doi.org/10.54941/ahfe1008298

DEM Cropper: A Web-Based Geospatial Processing System for Physical Terrain Representation

Loelle Lam and Nurit Kirshenbaum

University of Hawaii at Manoa, Honolulu, HI 96822, USA

ABSTRACT

Digital Elevation Models (DEMs) are foundational geospatial datasets used in Geographic Information Systems (GIS) for terrain analysis, environmental assessment, and spatial decision-making. However, transforming elevation data into physical terrain representations suitable for collaborative visualization and tangible geospatial interfaces often requires multiple specialized tools and significant technical expertise. This paper presents DEM Cropper, a browser-based geospatial processing system that integrates DEM ingestion, interactive spatial selection, terrain mesh generation, and fabrication preparation within a unified workflow. Users can upload GeoTIFF datasets, define arbitrary geographic regions through map-based interactions, and generate fabrication-ready terrain models directly in a web environment. The system also incorporates a terrain-aware partitioning method that subdivides large models into contiguous printable components while satisfying fabrication constraints. By lowering barriers to terrain model generation, DEM Cropper enables physical-digital geospatial visualization workflows in which terrain serves as a tangible interface for communicating and exploring spatial information.

Keywords: Geospatial visualization, Digital elevation models (DEM), Terrain modeling, Geographic information systems (GIS)

INTRODUCTION

Digital Elevation Models (DEMs) are foundational geospatial datasets used to represent Earth's surface and support applications including environmental modeling, urban planning, and geographic analysis. While 2D maps and digital 3D visualizations provide powerful analytical capabilities, physical terrain models offer an additional tactile representation of elevation and spatial relationships. Advances in additive manufacturing have made customized physical models increasingly accessible (Horowitz and Schultz, 2014), and physical terrain models can support spatial comprehension by engaging both visual and tactile senses (Hasiuk and Harding, 2016).

Recent systems have extended physical terrain models by combining them with projected digital overlays, allowing dynamic geospatial information to be displayed directly on a physical representation of terrain (Figure 1). This hybrid approach combines the tangible spatial context of physical models with the flexibility of digital visualization. However, creating customized

Received September 26, 2026; Revised October 31, 2026; Accepted November 6, 2026; Available online December 1, 2026

© 2026 The Authors. This work is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 License.
For more information, see https://creativecommons.org/licenses/by-nc-nd/4.0/

terrain models remains technically demanding, often requiring multiple GIS, modeling, and fabrication tools. Large models also introduce printer build-volume constraints that require terrain to be partitioned into smaller components. Existing partitioning approaches primarily address general 3D models (Luo et al., 2012) rather than terrain-specific 2.5D surfaces.

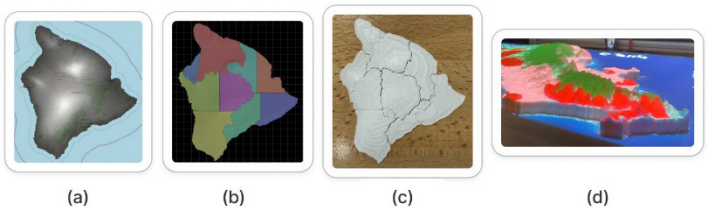


Figure 1: Comparison of terrain representation methods: (a) 2D DEM, (b) digital 3D visualization, (c) physical 3D-printed model, and (d) hybrid projection-based visualization.

To address these limitations, this work presents a browser-based system for converting DEM data into fabrication-ready terrain models. The system supports interactive spatial selection, terrain mesh generation, and terrain-aware partitioning for large models. By integrating these operations into a single geospatial workflow, the system reduces the technical barrier to creating customizable physical terrain representations for visualization and hybrid physical-digital geospatial applications.

The contributions of this work are: (1) a browser-based workflow for converting DEM raster data into printable terrain models; (2) interactive polygon-based selection of arbitrary geographic regions; (3) terrain mesh generation with interactive visualization; and (4) a terrain partitioning method that accounts for fabrication constraints and spatial continuity.

LITERATURE REVIEW

Physical terrain models have increasingly been explored as a medium for communicating geospatial information because they provide users with a tangible representation of elevation and landscape structure. Unlike traditional two-dimensional maps, physical models allow users to examine terrain from multiple perspectives and directly interact with topographic features. Prior work suggests that combining visual and tactile interaction can improve interpretation of geographic information and reduce cognitive effort associated with understanding terrain relationships (Hasiuk and Harding, 2016). Similarly, physical terrain models support educational and operational analysis by allowing users to inspect landscape features from any orientation and better interpret elevation differences (Solla, Casqueiro and del Cuvillo, 2020). These findings suggest that physical terrain models can support more intuitive exploration of geospatial information.

Despite these benefits, the process of generating physical terrain models remains dependent on technically complex workflows. Traditional approaches commonly rely on Geographic Information System (GIS) software and multiple processing environments. Chwiałkowski and Zydroń

(2024) describe workflows that integrate QGIS with plugins such as Qgis2threejs and DEMto3D to convert Digital Elevation Models (DEMs) into printable geometries. Similarly, Solla, Casqueiro and del Cuvillo (2020) demonstrate terrain generation pipelines involving QGIS, CloudCompare, and FreeCAD. While these approaches successfully produce printable terrain models, they require multiple manual processing steps and familiarity with GIS workflows. Related work by Chandra et al. (2022) extends GIS-based terrain visualization to browser environments through Three.js rendering but still requires substantial geospatial preprocessing.

To improve accessibility, several web-based systems have been developed that simplify terrain generation through browser interfaces. Systems such as TouchTerrain (Hasiuk et al., 2017; Harding, Hasiuk and Wood, 2021), Terrain2STL (Chamberlin, no date), Terrainator (Wilson, no date), and Map2Model (Smoggy3D, no date) reduce installation requirements and streamline model creation. However, important limitations remain. Many platforms do not support user-provided datasets, restrict users to predefined region selections, or offer limited support for preparing large terrain models for fabrication. A comparison of these capabilities is shown in Table 1.

Another challenge identified in the literature concerns fabrication constraints associated with additive manufacturing. Large terrain models often exceed printer build-volume limitations and therefore require partitioning into smaller components. Luo et al. (2012) proposed optimization-based methods for partitioning large three-dimensional models; however, these approaches were designed for general 3D geometries rather than terrain-specific 2.5D surfaces. Unlike the generic approach, terrain datasets present unique considerations for preserving geographic continuity and maintaining efficient model generation.

Collectively, prior work demonstrates substantial progress in terrain visualization and fabrication systems. However, existing approaches continue to exhibit limitations related to workflow complexity, constrained region selection, and inadequate support for fabrication preparation. These limitations motivate the need for a more integrated geospatial workflow that supports flexible terrain selection, user-provided datasets, and scalable terrain generation within a unified browser-based system.

Table 1: Comparison of web-based terrain model generation tools.

Capability	TouchTerrain	Terrain2STL	Terrainator	Map2Model	DEM Cropper
Supports user-provided DEM datasets	No	No	No	No	Yes
Supports arbitrary region shapes	Yes	No	No	Yes	Yes
Supports model partitioning	Yes*	No	No	Yes*	Yes
Exclude water region from model	No	No	No	No	Yes

(Continued)

Table 1: Continued.

Capability	TouchTerrain	Terrain2STL	Terrainator	Map2Model	DEM Cropper
Interactive 3D preview	Yes	No	Yes	Yes	Yes
Free STL export	Yes	Yes	No	Yes	Yes
Open source	Yes	No**	No	No	Yes

**Rectangular tiling only*
*** Available on GitHub with no license*

SYSTEM DESIGN

This section describes the structural design and functional workflows of the system, covering both the technical inner workings of system modules and the interactive workflows of the system users.

System Context

DEM Cropper converts Digital Elevation Model (DEM) datasets into printable terrain representations that can support physical visualization and projection-based interfaces. The workflow begins with elevation data, typically provided in GeoTIFF format, and transforms those data into three-dimensional terrain models suitable for additive manufacturing and subsequent hybrid visualization applications.

The overall process begins with DEM attainment and proceeds with terrain extraction, model generation, fabrication preparation, and physical production. After terrain generation, the resulting geometry can be exported as Standard Tessellation Language (STL) files and prepared for additive manufacturing using conventional slicing tools. Fabricated terrain models may subsequently serve as physical substrates for projected spatial information layers. The end-to-end workflow is illustrated in Figure 2.

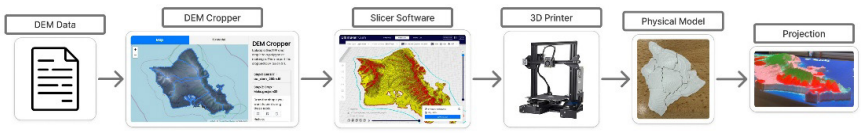


Figure 2: End-to-end workflow: from DEM to physical fabrication with projection.

System Design & Geospatial Workflow

The system transforms elevation data into fabrication-ready terrain models in five stages: (1) DEM ingestion, (2) spatial selection, (3) terrain generation, (4) terrain partitioning, (5) model export.

Unlike conventional GIS-based terrain workflows that require users to transition across multiple software environments, this approach integrates these functions into a unified browser-based environment. This design reduces fragmentation between geospatial preprocessing and physical model generation.

DEM Ingestion

The workflow begins with DEM ingestion, where users provide raster-based elevation data in GeoTIFF format. The system extracts elevation values and associated spatial metadata and renders the dataset in an interactive map, allowing users to inspect terrain features before model generation (Figure 3). The resulting elevation grid provides the basis for spatial selection and subsequent terrain generation.

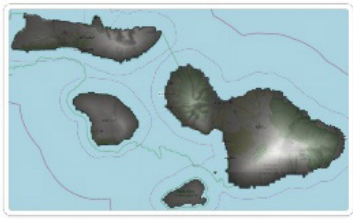


Figure 3: Uploaded GeoTIFF data are rendered as grayscale heightmaps.



Figure 4: Rectangle, polygon, and circle cropping tools are available to enable flexible selection.



Figure 5: Custom shapes can be imported via GeoJSON files.

Spatial Selection

Users define a geographic region of interest to extract from the DEM. The system supports rectangles, circles, freeform polygons, and imported GeoJSON geometries (Figures 4 and 5), allowing regions to be defined according to the geographic features or areas being investigated.

The selected geometry is converted into a binary mask aligned with the DEM raster (Figure 6). The geometry is transformed from geographic coordinates into raster coordinates, after which a point-in-polygon operation determines which raster cells fall within the selected region. Cells inside the boundary are assigned a value of 1, while cells outside are assigned 0. The resulting mask identifies the elevation data retained for terrain generation.

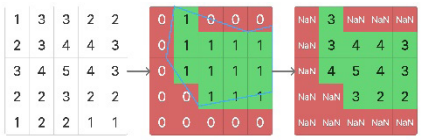


Figure 6: Raster cropping using binary masking.

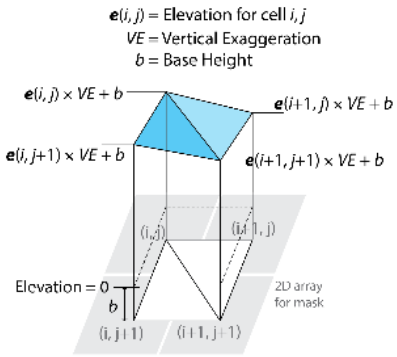


Figure 7: Triangular prism terrain unit defined over a grid spanning four raster cells. Elevation values e(i, j) at each cell are vertically exaggerated (VE) and offset by base height b to form the top surface, with corresponding base vertices at zero elevation, producing a closed convex geometry for mesh construction.

This process provides the key transformation between interactive geographic selection and raster-based terrain processing, allowing arbitrary geographic boundaries to be translated into terrain models.

Terrain Generation

The selected elevation grid is transformed into a 3D terrain mesh suitable for visualization and fabrication. Because the output must represent a physical object rather than an open surface, the generated terrain includes both the elevation surface and a base structure.

Terrain is generated using a cell-based representation in which elevation values from neighboring raster locations define the surface geometry. Each terrain unit is represented as a truncated triangular prism (Figure 7), producing a closed geometric structure with a terrain surface and base. The resulting units are merged into a unified terrain mesh for interactive visualization and export.

Users can inspect the generated model interactively and adjust parameters such as vertical exaggeration and base thickness before export.

Terrain Partitioning

Large terrain models may exceed the build volume of available 3D printers. The partitioning stage therefore divides the terrain into multiple printable components while preserving spatial continuity and limiting unnecessary

fragmentation. The partitioning operates on the elevation-grid representation and produces terrain sections that satisfy the specified fabrication constraints. The partitioning method is described in detail in the following section.

Model Export

The final terrain geometry is exported as STL files for use in standard additive manufacturing workflows. When partitioning is enabled, each printable section is exported as an individual STL file, allowing the components to be fabricated separately and assembled into the complete terrain model.

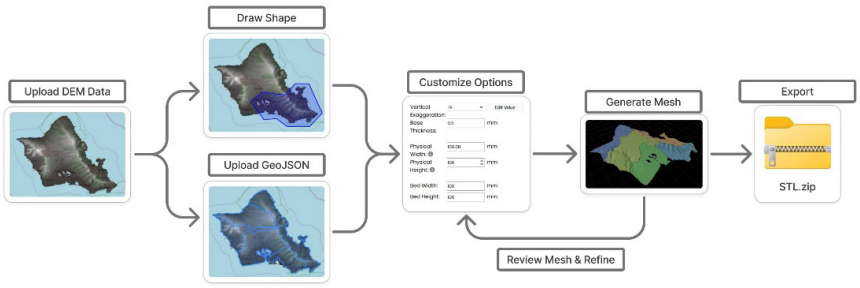


Figure 8: User workflow.

User Workflow

From the user's perspective, the workflow consists of selecting a DEM, defining a geographic region, configuring model parameters, generating the terrain representation, and exporting the resulting model (Figure 8). This sequence supports iterative adjustment between spatial selection, visualization, and physical-model preparation.

TERRAIN PARTITIONING

This section delves more into the algorithm we apply for partitioning the terrain when the desired physical model is too large for available 3D printers.

Overview

When physical terrain models are generated at large scales, their dimensions may exceed the build volume of available 3D printers. This is particularly relevant for large, table-sized terrain models intended for collaborative or multi-user visualization. To address this constraint, the proposed workflow partitions terrain into multiple contiguous components that can be fabricated independently and assembled after printing.

A common baseline is naive grid-based partitioning, which divides terrain into uniformly sized rectangular regions. As illustrated in Figure 9, this approach can produce fragmented components and does not account for terrain structure. In contrast, the proposed method generates terrain-aware partitions that better follow surface characteristics while reducing unnecessary fragmentation.



Figure 9: Comparison of naive rectangular partitioning (right) and the proposed terrain-aware partitioning (left). The naive approach produces small, fragmented components that are difficult to handle and assemble, whereas the proposed method generates larger, contour-aligned partitions that improve structural coherence and reduce part count.

The partitioning process operates directly on the raster representation of terrain and produces a label map in which each cell is assigned to a partition. The process is guided by three design objectives derived from prior research in additive manufacturing and spatial partitioning:

- **Printability:** Each partition must fit within the printer bed dimensions.
- **Continuity:** Each partition must form a contiguous region.
- **Part Uniformity:** Very small partitions should be avoided to reduce assembly complexity, so parts should be of a relatively uniform size.

The process consists of four sequential stages (Figure 10): (1) terrain-aware initial segmentation, (2) partition size enforcement, (3) contiguity correction, and (4) merging of small partitions.

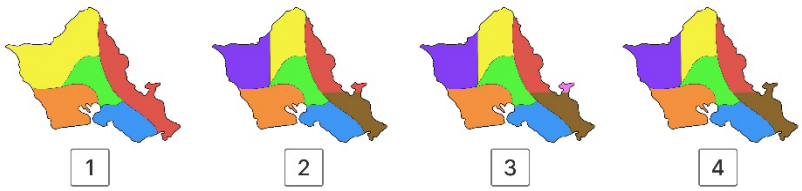


Figure 10: Stages of terrain partitioning: (1) informed initial partition generation, (2) partition size enforcement, (3) contiguity enforcement, and (4) small partitions merging.

Design Objectives

The partitioning criteria are informed by prior research in spatial partitioning, mesh segmentation, and additive manufacturing. Existing approaches emphasize the need to balance multiple objectives, including manufacturability, structural coherence, and assembly efficiency. Chopper, for example, partitions large objects into printable components while considering fabrication complexity (Luo et al., 2012), while subsequent

fabrication-aware approaches consider part count, structural soundness, and connector feasibility (van Beerendonk, 2024). Research in spatial partitioning similarly emphasizes compactness and continuity when satisfying competing objectives (Biswas et al., 2023; Liu and Cho, 2020), while fabrication-aware design highlights the need for components that can be reliably assembled while maintaining structural integrity (Song et al., 2015).

Building on these principles, this work adapts printability, continuity, and part uniformity to the raster-based, 2.5D structure of terrain. Rather than partitioning a general 3D mesh, the method operates directly on elevation grids to preserve spatial coherence while satisfying physical fabrication constraints.

Terrain Partitioning Method

The terrain partitioning method consists of four stages (Figure 10). The first stage generates an initial terrain-aware segmentation by grouping areas with similar local elevation variation rather than applying uniform rectangular tiling. Connected regions within these terrain classes form candidate partitions, while invalid or missing elevation cells are treated as background. Small fragmented regions are subsequently merged with neighboring partitions to produce a cleaner initial segmentation.

The second stage enforces printability by comparing each partition's spatial extent with the physical dimensions of the printer bed. Partitions that exceed these constraints are iteratively subdivided along their longer spatial dimension until the resulting regions satisfy the printer dimensions.

The third stage enforces continuity by identifying disconnected regions within individual partitions and separating them into independent components. This ensures that each resulting partition corresponds to a single connected terrain region suitable for fabrication.

Finally, the method merges excessively small partitions with neighboring regions when the resulting partition remains within the printer constraints. This reduces unnecessary fragmentation and produces a set of terrain components that are more practical to fabricate and assemble.

An example of the resulting partitioned terrain and its physical fabrication is shown in Figure 11.

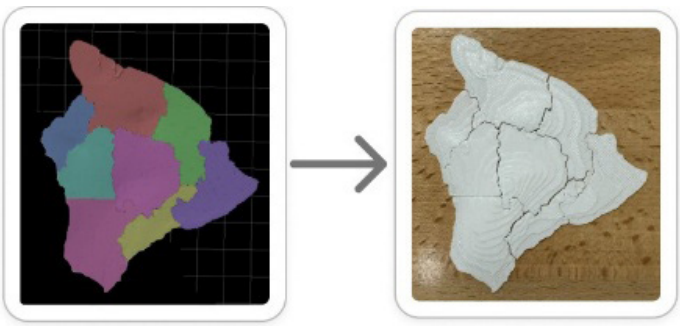


Figure 11: A 3D model generated by the terrain partitioning algorithm is subsequently fabricated via 3D printing.

DISCUSSION

This section discusses the application space for DEM Cropper as well as its limitations and potential future improvements.

Geospatial Applications

Beyond terrain model generation, the system can be viewed as infrastructure supporting broader geospatial visualization and decision-support environments. By converting raster-based elevation data into physical terrain models, the system lowers the technical barriers to creating tangible interfaces from geospatial data.

Public-sector organizations rely on Geographic Information Systems (GIS) and data analytics to inform urban development, disaster management, resource allocation, and infrastructure planning (Attah et al., 2024). Although GIS provides powerful analytical capabilities, its value in decision-making depends on the ability of stakeholders and citizens to understand and visualize the spatial implications of a variety of scenarios (Giuffrida et al., 2019).

Prior projects demonstrate the potential of projection-based terrain interfaces. Illuminating Clay (Piper, Ratti and Ishii, 2002) combined a manipulable physical terrain model with projected spatial information for landscape analysis. ProjecTable (Bui et al., 2024) used projection onto 3D-printed physical terrain to communicate renewable energy transition scenarios in Hawai‘i, while ClimaTales (Halim et al., 2026) used projection mapping and 3D-printed physical terrain to communicate climate patterns and environmental change. These systems demonstrate the broader value of physical terrain as a spatial interface in which digital information can be presented while retaining geographic and topographic context.

DEM Cropper addresses a foundational requirement of such environments: the creation of accurate, customizable terrain models from elevation data. Rather than providing a complete projection-based decision-support environment, the system provides a geospatial transformation layer between elevation datasets and physical terrain representations. This creates opportunities for future integration with projected transportation, infrastructure, land-use, environmental, or hazard-related datasets in planning and public-engagement contexts.

More broadly, the system demonstrates how geospatial data can be translated from conventional digital GIS representations into tangible spatial interfaces. This positions DEM Cropper at the intersection of GIS, geospatial visualization, and human-centered interaction, with potential applications in spatial communication, collaborative exploration, education, and public-sector engagement.

Limitations and Future Work

The primary limitation of this work is that it evaluates the design and functionality of the terrain-generation workflow rather than user outcomes. The study does not measure whether physical terrain models improve spatial understanding, learning, collaboration, or decision-making. Future work

should therefore include user studies evaluating the effectiveness of DEM Cropper-generated models in relevant application contexts.

The system also does not implement a complete projection-based visualization environment. Although prior systems such as Illuminating Clay, ProjecTable, and ClimaTales demonstrate potential applications of physical terrain interfaces, integrating DEM Cropper directly with projection-mapping systems remains future work.

Finally, the terrain-partitioning method is deterministic and rule-based and may not produce globally optimal solutions. Future research could evaluate alternative optimization approaches and incorporate additional fabrication criteria. The current workflow also focuses on terrain derived from DEMs; integrating additional geospatial layers such as transportation, infrastructure, land-use, and environmental data represents another opportunity for future development.

CONCLUSION

This work presented DEM Cropper, a browser-based geospatial workflow that transforms Digital Elevation Model (DEM) datasets into fabrication-ready terrain models through integrated DEM ingestion, flexible spatial selection, terrain mesh generation, terrain-aware partitioning, and model export. By connecting raster-based geospatial data with physical terrain representations, the system provides a unified workflow for creating customizable terrain models while addressing fabrication constraints such as printer build volume. Beyond terrain fabrication, DEM Cropper provides infrastructure for tangible geospatial visualization and projection-based applications in which physical terrain can serve as a spatial foundation for communicating and exploring geographic information. Future work should evaluate these applications empirically, including the effectiveness of physical-digital terrain interfaces for geospatial communication, analysis, and decision-making.

REFERENCES

Attah, R. U. et al. (2024) Leveraging geographic information systems and data analytics for enhanced public sector decision-making and urban planning. *Magna Sci Adv Res Rev*, 12(2), pp. 152–163.

Biswas, S. et al. (2023) Memetic algorithms for spatial partitioning problems. *ACM Transactions on Spatial Algorithms and Systems*, 9(1), 1–31.

Bui, T. et al. (2024) Illustrating transition scenarios to renewable energy in hawaii with projectable. *arXiv preprint arXiv:2412.10969*.

Chamberlin, T. (no date) 'Terrain2stl'. Available at: https://jthatch.com/Terrain2STL/ (Accessed: 16 April 2026).

Chandra, S. et al. (2022). Visualization raster based 3d digital elevation model on web using qgis. *International Journal of Computer Science and Mobile Applications IJCSMA*, 10(5), 1.

Chwiałkowski, C. and Zydroń, A. (2024) Preparation of the digital elevation model using open source geographic information systems tools for 3d prints. *Polish Cartographical Review*, 56(1), 32–45.

Giuffrida, N. et al. (2019) Mapping with stakeholders: An overview of public participatory gis and vgi in transport decision-making. *ISPRS International Journal of Geo-Information*, 8(4), 198.

Halim, M. et al. (2026) Climatales: A physicalization story-telling tool for climate patterns. *Proceedings of the 10th ACM International Symposium on Pervasive Displays*, 1–4.

Harding, C., Hasiuk, F. and Wood, A. (2021) Touchterrain—3d printable terrain models. *ISPRS International Journal of Geo-Information*, 10(3), 108.

Hasiuk, F. and Harding, C. (2016) Touchable topography: 3d printing elevation data and structural models to overcome the issue of scale. *Geology Today*, 32(1), 16–20.

Hasiuk, F. et al. (2017) Touchterrain: A simple web-tool for creating 3d-printable topographic models. *Computers & Geosciences*, 109, 25–31.

Horowitz, S. S. and Schultz, P. H. (2014) Printing space: Using 3d printing of digital terrain models in geosciences education and research. *Journal of Geoscience Education*, 62(1), 138–145.

Liu, Y. Y. and Cho, W. K. T. (2020) A spatially explicit evolutionary algorithm for the spatial partitioning problem. *Applied Soft Computing*, 90, 106129.

Luo, L. et al. (2012) Chopper: Partitioning models into 3d-printable parts. *ACM Transactions on Graphics (TOG)*, 31(6), 1–9.

Piper, B., Ratti, C. and Ishii, H. (2002) Illuminating clay: A 3-d tangible interface for landscape analysis. *Proceedings of the SIGCHI conference on Human factors in computing systems*, 355–362.

Smoggy3D (no date) 'Map2model'. Available at: https://map2model.com/ (Accessed: 16 April 2026).

Solla, M., Casqueiro, C. and del Cuvillo, I. (2020) Approach to generate 3d-printed terrain models using free software and open data sources: Application to military planning. *Computer Applications in Engineering Education*, 28(3), 477–489.

Song, P. et al. (2015) Printing 3d objects with interlocking parts. *Computer Aided Geometric Design*, 35, 137–148.

van Beerendonk, P. (2024) An improved partitioning algorithm for 3d printing.

Wilson, D. (no date) 'Terrainator'. Available at: https://terrainator.com/ (Accessed: 16 April 2026).