Exploring Less Geometric Landfill Slopes through Parametric Digital Modelling

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Abstract: Massive and visually disruptive landfills in urban areas can potentially be seen by hundreds of thousands of people daily. Even after landfill closure, constructed slopes and ridgelines can contrast with the surrounding terrain because of their signature geometric form. This paper uses three landfills in Southern California to demonstrate the need for better visual mitigation, test the sculpting of landfill slopes through parametric digital modelling, and then discuss how the process can be enhanced for real-world application that improves visual quality while meeting engineering requirements. This is an area where landscape architects can make greater contributions in mitigating the visual impacts of landfills.

Keywords: Landfill aesthetics, landfill slopes, rhino modelling, digital terrain modelling, visual impact assessment

1 Introduction

Landfills are the primary way that non-recyclable municipal waste is managed. Incineration is eschewed due to the introduction of carbon particulates and a harmful airborne brew of potentially carcinogenic chemicals associated with plastics and other modern manufactured materials. The ever-growing volume of waste is also a major concern and landfills can be massive. Besides the large physical dimensions of landfills, the process of land filling requires a substantial investment in time, expense, and effort to locate suitable sites, meet stringent permit requirements, prepare the site for liquid containment and methane gas extraction, manage daily fill operations, and mitigate a full range of impacts. For these reasons, the trend is towards fewer, but larger landfills (EPA 2014, 2-11).

Many landfills are geometric in shape and the planar sides and mesa-like top can be recognized from miles away. In urban areas, the number of viewers can be numbered in the hundreds-of-thousands, and unsightly views or the presence of landfills can negatively impact property values ranging from 3-7% (REICHERT et al. 1991, BOUVIER et al. 2000, READY 2005). Moreover, the scale of urban landfills can be dominating. For example, Puente Hills landfill in Southern California, which closed in 2013, has a footprint of 283 ha (700 ac) and is 150 m (490 ft) in height. Counting buffer land, the facility consumes 526 ha (1,300 ac).

1.1 Objective

Landfill design and operations generally fall within the realm of engineering and scientific consultants. Landscape architects become involved when considering landfill aesthetics. Typically, these activities are related to landcover planting and the preparation of visual analyses and simulations when preparing environmental impact documents prior to landfill permitting. As "shapers of land", the objective of this paper is to explore how landscape architects might become more involved in the earlier stages of landfill design through enhanced digital modelling so the *landfill shape* upon closure can better blend with the terrain context.

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1.2 Extending the Role of Landscape Architects?

The origin of this paper derives from the primary author's environmental consulting work preparing visual assessments for two landfills in southern California: Elsmere Canyon Landfill (early 1990s) and Simi Valley Landfill Expansion (mid 2000s). In both cases, the landfills were of the canyon/valley type. Extensive 3D computer modelling, GIS-based viewshed mapping, and before/after photo simulations (Fig. 1) were conducted to determine visual exposure and estimate visual impacts as viewed from key observation points (KOPs). These points were public gathering areas like parks, major travel ways, and nearby residential and commercial areas at distance ranges from 0.3 to 8.5 km (0.2 to 5.3 mi).

Fig 1: Before and after simulations for the Simi Valley landfill expansion as viewed from a residential area about 2.3 km (1.4 mi) away. This simulation conveys the massive scale and visibility of the landfill, and the need to better blend landfill slopes with undisturbed topography beyond conventional reclamation practices (SAIC 2010: Original images by H. Hahn).

In the case of Elsmere Canyon Landfill, the permit was denied after much public opposition. Simi Valley Landfill was already an operational landfill in mid-life, and the expansion was approved after a multi-year environmental review process which addressed public concerns. Even though the expanded landfill conformed to conventional engineering design, the primary author wondered if landfill slopes could be made to appear less geometric and better blend with contextual terrain. Instead of involving landscape architects to assess or mitigate visual impacts after landfill design is nearly complete, the role of landscape architects could be expanded to perform landform sculptural studies earlier in the design process. Closely coordinating with engineers, slope sculpting would still need to meet fill volume requirements, access road routing, methane gas piping, and comply with efficient daily operations. This paper only explores landform, and does not address vegetation, atmospheric conditions, or other factors affecting visual quality.

2 Concept Overview

2.1 Enhanced Slope Sculpting to Reduce Visual Impacts

The goal of the "sculpting" process is to introduce more slope undulation into uniform slopes to replicate convex finger ridges and concave drainages found in contextual terrain, but to a lesser degree to still support engineering requirements. This will increase tonal variation (shade/shadow) patterns which will better blend with contextual, undisturbed terrain. As viewing distance increases and atmospheric factors become more pronounced, tonal contrasts are more important to visual mitigation compared to texture or hue variations.

2.2 Slope Sculpting Procedures

Landfill form emerges as systematic lifts (layers) approximately 8-20 feet thick. Each lift is composed of cells where daily to weekly accumulation of refuse is compacted and covered with 6” of soil. Once cell placement reaches the perimeter of the lift, the outer slope is shaped at a not to exceed 1.5:1 ratio. A series of 15’ wide benches are also added per EPA regulations (EPA 1988, 62). Under the sculpting concept, none of these standard filling and grading operations would be appreciably altered until the lift edge nears. At this point, GPS-enabled earth moving equipment would grade an undulating edge, that over years, would emerge as finger ridges or drainages on the slope much like 3D printing. The precision of GPS is essential to accurately locate and place cover material along the undulating lift perimeter where the eventual slope form is not immediately apparent.

Towards this goal, several additional steps are needed beyond traditional engineering design:

1) Numerically determine the slope gradient and vertical/horizontal convexity of the surrounding topography (usually applicable to canyon/valley landfill types) for use as a contextual referent.

2) Iteratively sculpt a 3D landfill computer model where exposed sides more closely replicate contextual slopes and topographic features, and then shape a rounded cap or ridgeline profile that undulates as opposed to a flat mesa. The model footprint may have to be slightly expanded to offset anticipated volume losses compared to conventional geometric forms, or the overall height increased (LAW et al. 2008).

3) Transfer the preliminary sculpted model into Civil 3D or other engineering software for detailed design and implementation documentation.

4) Prepare a grading plan that can be uploaded into GPS-enabled refuse/earthmoving equipment to guide landfill slope shaping over decades.

3 Methods

There are multiple methods to analyze undulations in topographic surfaces to set numeric base conditions for slope modelling: slope aspect and gradient, planform curvature, profile curvature, topographic openness, and landscape roughness. Some numeric techniques include fractal dimension indexing (FRAC) (CUSHMAN et al. 2005, 103-104; MCGARIGAL & MARKS 1995), standard deviations of contour line segments, and topographic position indexing (TPI) (JASIEWICZ & STEPINSKI 2013, MOKARRAM & HOJATI 2016).

To identify a landfill as a test case for parametric digital sculpting, Zhong (2020) inventoried 43 landfills including 14 active and 29 closed landfills larger than 100 acres in Los Angeles County. As part of the review, FRAC indices were calculated for the landfills to assess how geometric the slopes appear and identify candidate landfills for further analysis.

After candidate landfills were reviewed, attention turned towards which digital modelling software might be most useful. WESTORT (2015, 225-226) discusses the need for improved landform design tools which are 3D, provide geometric control, are easy to handle, provide quick response time, and are quantitatively accurate. Furthermore, the ability to iterate before and during the construction [or design] phase is desirable. From our experience, Autodesk Civil 3D meets most of the criteria for Digital Elevation Modeling (DEM) but is deficient in interactive surface sculpting. A spline modeler like Rhino is better suited for this purpose and offers parametric automation through Grasshopper terrain plug-ins like Docofossor, Bison, and TOPO kit. Upon initial review, it appears that these plug-ins do not offer the sculpting features/control as envisioned without additional customization.

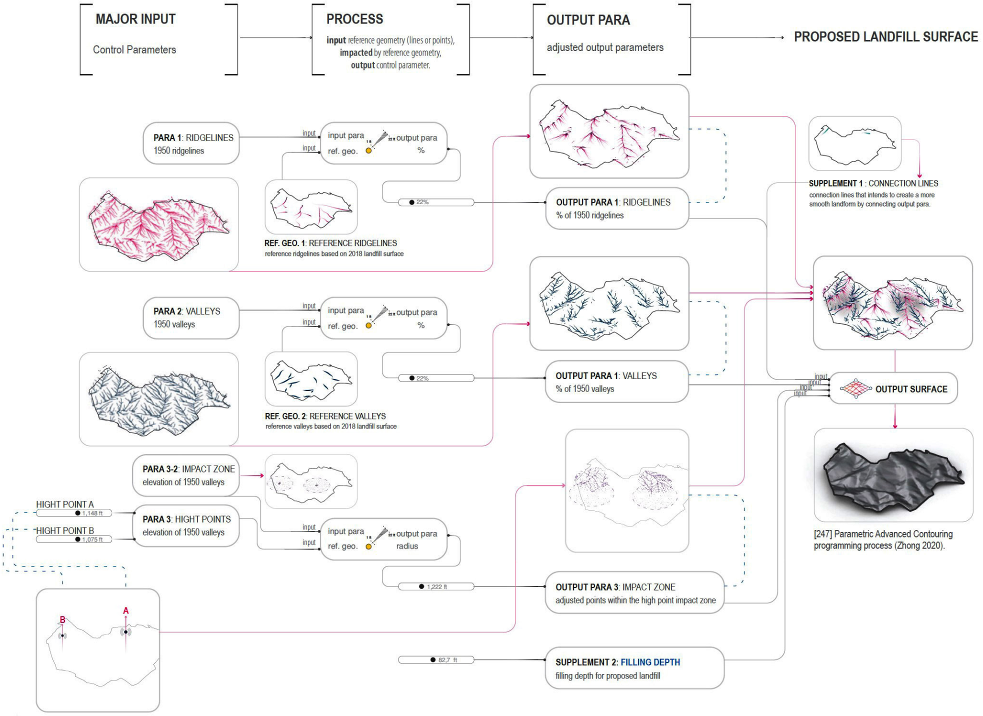

Fig. 2: Rhino/Grasshopper parametric control process for sculpting landform derived from skeletal ridgeline structure of pre-landfill conditions (ZHONG 2020)

To test how inclined finger ridges can be introduced to geometric landfill slopes while still maintaining landfill capacity, ZHONG (2020) used the closed Puente Hills Landfill to prototype a hybrid manual-parametric landform sculpting process using a customized Rhino/Grasshopper script using 3D control framework (Fig. 2). Preparatory work consisted of manually digitizing major ridgelines, finger ridges, and intervening drainage flow lines from the undisturbed 1950 topography as a fully detailed referent of pre-landfill conditions. Points from this skeletal landform structure were then filtered through a Grasshopper script to interactively reduce ridge and valley point detail as a percentage. Two highpoint locations from the 2018 landfill top deck (or intended height of a planned landfill) served as landfill closure (2013) height parameters. Once parameters were set, a simplified surface was interpolated through the points. Using various combinations of 22%, 66%, and 88% remaining ridgeline and valley points, seven surfaces (P1-P7) were generated for comparison. Processing per iteration took about 4-6 hours.

4 Results

After the manual-parametric methods were established to generate landform alternatives, further modelling exploration was undertaken. For comparison against standard landfill design, two planar geometric surfaces (G1-G2) and three advanced contoured surfaces (A1-3) were manually defined through contours and generated through Rhino. The G1 and G2 surfaces typified landfills of low visual quality and the A1-3 surfaces represented enhanced landfills having some amount of slope undulation (Fig. 3).

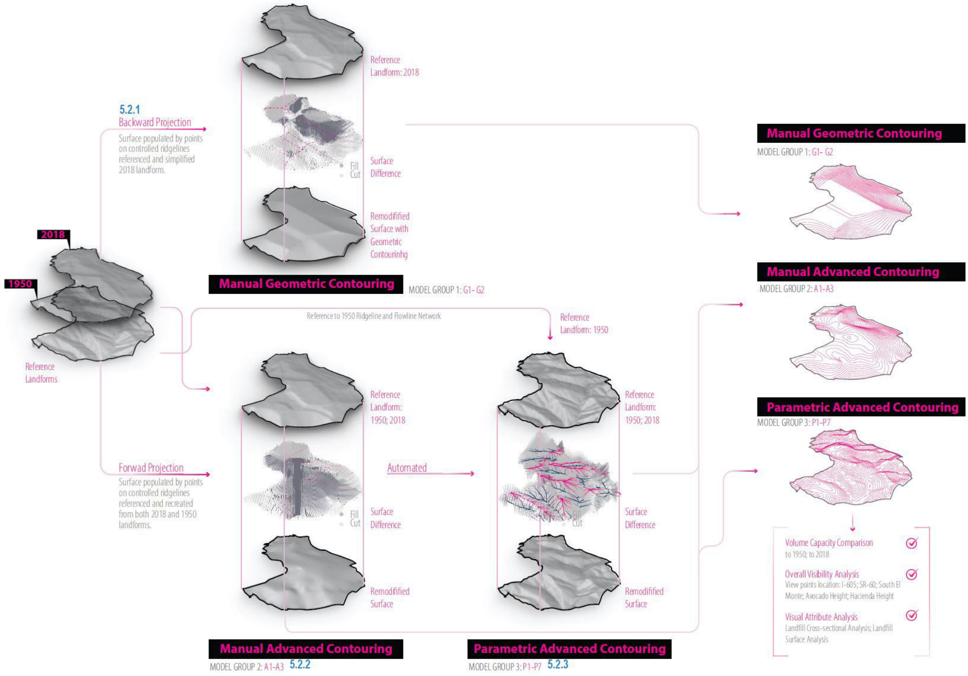

Fig. 3: Results were compared for manual geometric, manual advanced contouring, and parametric modelling of landfill configurations against 1950 existing topography and the 2018 shape configuration of the Puente Hills landfill (ZHONG 2020)

Once the 12 alternative landform surfaces were modelled in Rhino, the surfaces were exported into Civil3D for volume calculations. Two sets of volumetrics were compared: 1) the 1950 pre-landfill referent surface compared to the 12 Rhino alternatives (2020) for total volume capacity; and 2) the 2018 DEM dataset (2013 closed landfill conditions) compared to the same 12 Rhino alternatives. The latter comparison is intended to directly reveal net volume gain/loss by introducing more undulations to constructed landfill surfaces. Of the 12 alternatives, three showed capacity gains: A3 (+5%), G2 (+24%), and G1 (40%). Surface undulations for the closed landfill and among the 12 alternatives were also compared through slope mapping and aspect mapping which quickly made differences visually evident.

5 Discussion and Conclusions

Modelling results reveal that although simplified, the P1-P7 parametric surfaces too closely resemble the complexity of the 1950 topographic referent. P1-P7 volume capacity was not sufficient, slope angles were not constrained to the 1.5:1 standard (not part of script), and excessive slope undulations/aspect variation would likely make implementation difficult. As expected, introducing more surface undulations decreased landfill volume capacity for most alternatives compared to the more geometric landfill forms.

Through this exploratory test, however, advancements were made in parametric surface modelling that enabled rapid iteration, testing, and comparison of landfill alternatives. The A3 alternative demonstrates that more slope undulations *can be* introduced to improve landfill aesthetics while still maintaining capacity volume. Rapid iteration, as demonstrated through 12 alternatives, is essential in finding the right balance of improved aesthetics, capacity volume, and other engineering factors to be tested in future work.

Results demonstrate the potential of applying digital sculpting tools to enhance landfill slopes to make them appear less geometric and planar. Artistic manipulation must be coupled with engineering requirements to maintain slope stability, constructability, and volume capacity. GPS enabled refuse/earth moving equipment can provide the precision and locational accuracy across large lift expanses to achieve more naturally appearing “outer shell” forms.

Making progress to sculpt landfill surfaces iteratively and more freely for aesthetic purposes partially fulfilled the initial objective of this paper. Full realization of the objective requires landscape architects to better understand the complexity, timing, and workflow commensurate with landfill design and operations if they are to be involved. Based on past professional experience with landfills, many engineers, technical consultants, regulatory agencies, and environmental assessment specialists are involved, and the design and permitting requirements are substantial. Reducing visual impacts is a worthwhile goal but knowing *when* and *how* optimized landform modelling with a greater emphasis on aesthetics can be introduced into the design process is challenging. To be cost- and time-efficient, it needs to be used early in the process, offer rapid iteration, meet engineering requirements, and then be passed off to others for technical refinement. At the landfill operational stage, extra edge/slope requirements must also be safe and compatible with the myriad of choreographed activities taking place on the working deck.

Several limitations are evident: more documented research is needed regarding the long-term aesthetic impacts of landfills upon closure after vegetation has matured; more parametric controls are needed for slope shaping, the Rhino to Civil 3D transference needs to be more streamlined; and most importantly, a test case involving engineers needs to be identified.

6 Future Work

Future improvements are needed to incorporate more parametric control of slope undulation and shaping. Additional ridgeline control is also needed for shaping the landfill cap to avoid a mesa-like appearance. A hybrid between the P and A models is envisioned.

In addition to ridgeline controls, select parametric contours (splines) could be added as control features to parameterize surface undulation. Parameters would be based on sinuosity which is simply calculated by dividing the sinuous contour length by the straight distance between the contour line endpoints. Calculating sinuosity is typically associated with stream systems but can also be applied to characterizing landfill slopes where FRAC and TPI indices are too general to control shaping. Referencing the sinuosity index of contextual landform, a few parametric contours placed at strategic locations at the edge of landfill lifts could seed the formation of finger ridges. The finger ridges would become more apparent as the landfill height grows with each successive lift much like 3D printing.

Differences in slope sinuosity can be illustrated using existing portions of the Lopez Canyon landfill in Sylmar, California (Fig. 4). In this 3D view of the 2016 DEM surface, a contour line (L1) traces undulating slopes of the contextual foreground slopes, whereas the more linear contour line (L2) traces the constructed geometric slope of the landfill face rising above the foreground ridge. The calculated sinuosity indices (SI) are 1.44 and 1.19, respectively. In a revised parametric model, the SI of L2 could be adjusted to resemble the undulations of L1 more closely while still allowing for proper slope benching, access road construction, and methane gas piping. This will be tested as the Rhino/Grasshopper script is improved.

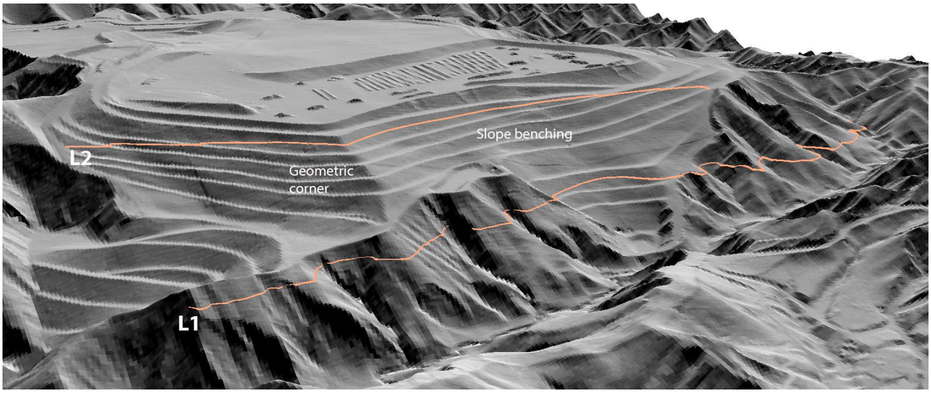

Fig. 4: Sinuosity (1.44) of contour line (L1) tracing across finger ridges of undisturbed contextual topography compared to sinuosity (1.19) of contour line (L2) of constructed landfill slope (DEM processing and image by H. Hahn; 1m DEM data downloaded from USGS 2020)

These future improvements should enhance modelling capabilities, increase ease-of-use, and provide better integration with software used to prepare construction documents. Discussions are also needed with landfill designers with regards to landfill operations, sequencing, and overall feasibility of this envisioned approach to landfill aesthetics and visual mitigation.

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