Eroding Terrains: Developing Computational Design Tools for Interactive Site Erosion

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Abstract: Landscape erosion processes can be problematic and are universal in their effect on all forms of landscape contexts and conditions. Hydrological erosion processes are important features of ecologies, yet are often extremely problematic, and can be exacerbated by climate extremes, weather events, animal and human activities, and especially transformations through agricultural processes. This research documents and proposes computational design tools and methods for erosion simulation in real-world scenarios. While there are many examples of soil erosion modelling in the life sciences and engineering fields, they are rarely applied at the detailed scale of the landscape-, architecture- and design disciplines. The work attempts to leverage erosion processes for design by creating new workflows inside familiar design and modelling programs. Applications may vary between agricultural land and areas of accelerated climate change, however, the test case for this application is in a fire-affected landscape particularly prone to erosion. This research seeks to unite site investigation and survey techniques with interactive erosion modelling within AEC design software. By introducing intuitive ways to model erosion processes mitigation becomes possible within the landscape analysis and design process, creating opportunities to avoid erosion before it occurs.

Keywords: Site surveying, erosion simulation, site/office hybrid techniques, iterative terrains

1 Introduction

Erosion is a fundamental landscape process that underlies all landform generation. In combination with transport and sedimentation, it is integral to all landscape processes and their inhabited ecologies (KONDOLF 1994). Despite many advancements in the various ways in which humans have formed and manipulated the earth, erosion remains process we still struggle to work with. How we counter the degenerative effects of erosion have barely changed over the last century (BATES & ZEASMAN 1930). This research is particularly focused on hydrological erosion as one of the key forms of erosion affecting landscapes worldwide at an accelerating rate due to climate change and land-use practices. The perceived demand for such techniques comes from both an observed lack of such analyses executed in the AEC industries, and the direct demand for such methods from within parallel research projects (MELSOM 2022). The parallel research projects inform this case study and initial practice model for this technique, namely the specific and heightened erosion issues faced by post-fire landscapes, although the techniques are equally applicable to a wide range of other landscape and built environment circumstances, such as disused agricultural and cleared landscape plots, de-vegetated drought-affected areas, and building construction sites. The work documents the current progress in developing specific tools for common erosion models at a local site scale, leveraging high-resolution user-generated site models.

Recent shifts in weather patterns, storm event frequency and magnitude, connected with ongoing climate change exacerbates the loss of soils as a key societal issue that already dates back centuries (MONTGOMERY 2012). It commonly results in the loss of arable land, in-

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creased landscape disturbance, the destruction of ecological systems, as well as negative effects on the built environment. Erosion simulation is an answer in the field of civil engineering, providing insight to where and how it might occur. Large to medium scale modelling is widespread, and often leverage GIS or proprietary and specialised modelling software solutions (MAY et al. 2005, ARGENTIERO et al. 2021). Furthermore, there is also some scepticism in the relevance and accuracy of such simulations at territorial scales (MONDA et al. 2017). Nevertheless, these models tend to focus on the territorial or catchment scale, distinctly abstract from the detailed site scale and restricted to the realm of specialised engineering applications and computation intensive instrumentation (KANITO & FEYISSA 2021).

At the design scales there are clear and compelling examples of methods that propose to work *with* avalanches and sedimentation events instead of against it. Here materials are redistributed as they erode or arrive on site (HURKXKENS 2021). The potential to combine detailed site data with predictive or preventative erosion modelling provides many compelling avenues for landscape management, generative possibilities, effective hybridisation of erosion, sedimentation, and design.

2 Iterative Erosion Modelling

Hydrological erosion types follow several generally established patterns and types, each often the precursor for the next: splash, sheet, rill, gully, bank and stream, ordered by increasing scale. Rill and gully erosion have been isolated as the most useful for this research, to generate a simplified simulation tool. Existing specialised applications in earth engineering have formed both the basis for this selection and a model for confirmation of applicability (HANCOCK et al. 2008). As can be seen in such precedents, high-resolution site data is required in order to generate relevant results. Detailed, recent models are a necessary starting point, with medium to high-resolution laser scanning or photogrammetry a base requirement. Due to the nature of rilling scale erosion sites, photogrammetry is particularly interesting as it excels in open ground, un-vegetated areas, allowing a consistent accuracy of 10cm down to 2cm. Open agricultural fields, mining landscapes, and post-industrial sites are suitable examples of high-resolution photogrammetry subjects, or in the case of this research, post-fire affected sites, cleared of foliage and vegetation canopy. The site of Rosedale, NSW, Australia was chosen as an ideal candidate for such a fire-affected erosion modelling scenario (Figure 1).

A simplified model closely mimics the established model (KANITO et al. 2021, HANCOCK et al. 2008) yet allows for a close to real-time feedback loop, and the integration of iterative workflows. To this end, Rhinoceros was chosen as a base software, with the integration of scripting and plugin development to provide a seamless connection with three-dimensional design software that is both intuitive and an industry standard. Rather than analysing the model outside the design software, it is compatible with other AEC design software and methods, without interrupting the design process. It is also compatible with GIS software and various spatial data types. This simplified process can integrate other landscaper factors such as soil characteristics, barriers, and vegetation to improve the accuracy of the simulation further.

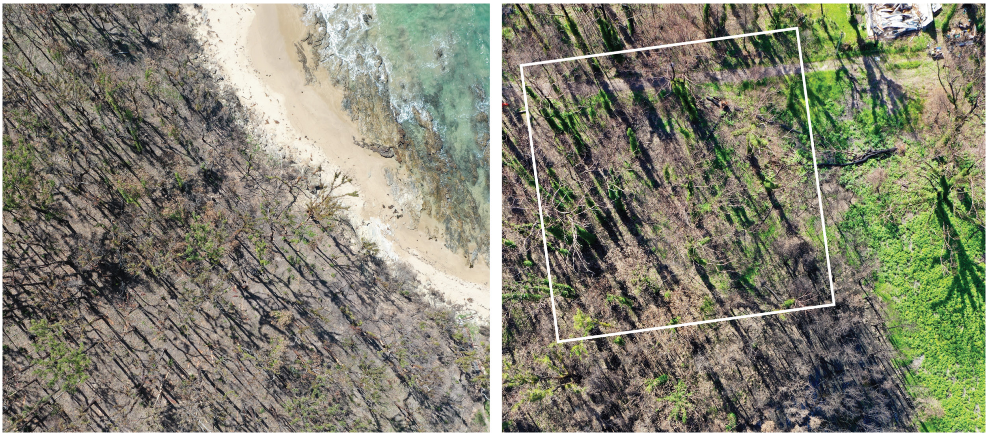

Fig. 1: Post-fire erosion landscape, Depot Bay, NSW Australia 2020 (images: Author)

The concept of iteration is also considered an important simulation criterion within the design space, in this case, differentiated into two iterative models, integral and event iteration:

Integral Iteration describes the case in which the eroded model accounts for erosion and deposition within the same continuous modelling cycle, with eroded areas having a compound effect on their continued erosive processes, rather than acting on existing site characteristics alone, and allowing for changes to the site to be made during simulation.

Event Iteration modelling allows for separate events, with a shift in intervening characteristics (vegetation, topography, physical intervention). This model allows for multiple hydrological events to take place separately, with shifts in the intervening period. This is an important factor in many erosion-prone landscapes, as long-term erosion effects are often generated through multiple or repeated erosion events that are incremental, rather than occurring in one discrete event.

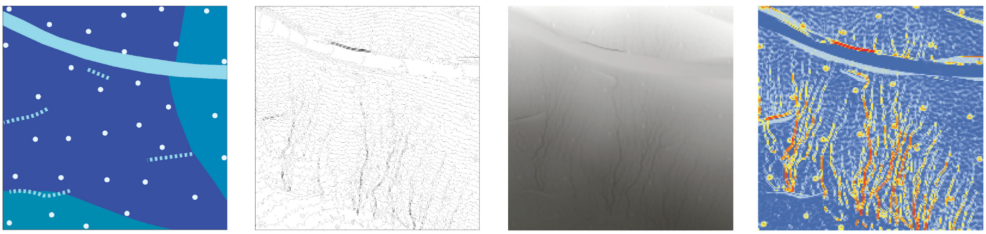

Fig. 2: Combination of Layer inputs Soil Texture, Erosion Resistance, Terrain Slope, Terrain Roughness, Terrain Slope and resulting erosion results

Terrain Characteristics also play a key role in understanding the processes of erosion. Many factors affect its course over the surface in landscape terrain models and have therefore been included in the erosion model, with varying levels of integration (Figure 2).

Soil Texture is a key characteristic in erosion models. Different soil types erode and deposit at varied rates, and the standard simulation technique of a reference raster image has been applied.

Terrain Slope and rate of slope change are fundamental erosion characteristics, regardless of soil type, as they affect the speed and acceleration/deceleration of water movement and therefore energy of the water, and its propensity to either erode or deposit material. To this point, only slope angle has been implemented.

Terrain Roughness at this site scale. Here individual terrain details such as vehicle tyre tracks, animal marks and soil or rock texture can have a huge influence on erosion patterns. Not to be confused with soil texture, additional roughness or triggers to erosion can be included either as proxy mesh, with noise, or as a raster image.

Erosion Resistance is the demarcation of areas that physically cannot erode or are otherwise resistant to erosion due to solid barriers, vegetation, root systems, or other physical hindrance. These areas can be either physically modelled or marked with images, allowing a graduated effect.

Table 1: Multiple terrain characteristics, layers, and their effects

Layer Characteristics	Layer Type	Test Site Conditions	Test Site Layer
Soil Texture	raster image (input)	consistent on site, added	Soil Texture
Terrain Slope	calculated in plugin	consistent, variations at detailed (5×5m) scale	0-7° site scale, 0-38° rill scale
Terrain Roughness	mesh / image (input)	high-resolution photogrammetry mesh, no additional details added	2500×2500px raster; 2cm res
Erosion Resistance	polyline / image (input)	key site elements limited to surface tree trunk / roots and surface geology	43 trees 6 rock formations (polyline)

Each of these terrain characteristics has been integrated into the workflow to form a working model for a limited range of case studies (Table 1). Surface water flow calculation is based on detailed DTM data and simplified erosion simulation using reference parameters implemented with the computational terrain modelling plugin. Preliminary simulations assume a homogenous substrate, although the overall resistance characteristics to erosion can be manipulated. Additional testing and verification would be required for broader applications with accurate and repeatable results.

3 Surveying and Erosion Modelling Tool

The implementation and testing of the erosion simulations have centred around specific post-fire landscapes. These make appropriate sites, as they are often immediately susceptible to real erosion following an intense fire event. Erosion in these landscapes presents a massive issue for many authorities and communities. Analysis conducted in such landscapes has determined that up to 50 times more erosion can take place in an extremely fire-damaged landscape than in one marginally affected by fire, as well as many other mitigating factors (TULAU et al. 2015). To survey the affected terrain, there are precedents for UAV imagery and its use in general erosion mapping and simulation (MISTHOS et al. 2019). This survey method functions well in circumstances where erosion risk is high, due to lack of ground cover and exposed terrain. It also enables successive landscape surveys and allows for the mapping of landscape change and subsequent model adaptation. In addition, reference layers for erosion resistance can be generated from this data. In this case study, industry-standard photogrammetric software – Agisoft Metashape – was used for this stage of research, however, the delineation of the scanned site and predetermined route may aid in generating more accurate results with repeated scans of the same site, documenting its evolution and supporting iterative model generation. The required resolution and detail of the test site required a relatively low altitude (40m) scan height with a high overlap of 80% in both directions, with an angled camera (75°) flying in a gridded pattern around tree-bases (a common area of photogrammetric error).

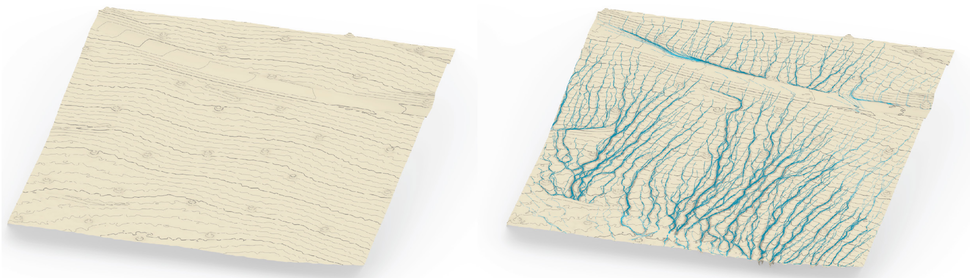

Fig. 3: Example of first and final frames from rill simulation on site-based terrain model

The simulations are built on top of Docofossor, a terrain modelling plugin for the visual scripting environment Grasshopper of Rhino 3D (HURKXKENS et al. 2019). It uses regular raster grids as underlying data-model for its terrain representation. This enables simple modelling operations in cut and fill using distance functions. Like the plugin, the erosion simulations make use of build-in class methods from RhinoCommon or via the Rhinoscript python implementation to compute the grid values.

The implication allows for animation and simulation of any part or any duration timeline. For detailed areas of the case study site (Figures 3) of around 50 x 50 m, animation frames can be calculated in less than 5 seconds on a standard workstation set-up, facilitating an optimal simulation-to-design workflow. When compared with large-scale surface water flow, the results demonstrate that a laminar surface concept of layered, continuous water supply and movement works well to imitate site-observed erosion phenomena in scale, extent, and pattern (Figure 4). Within the chosen case-study typology of fire-affected areas, there are ample examples and areas for verification and refinement of the erosion models in various soil and surface conditions. The varied performance in differing substrates is an area for further research and study.

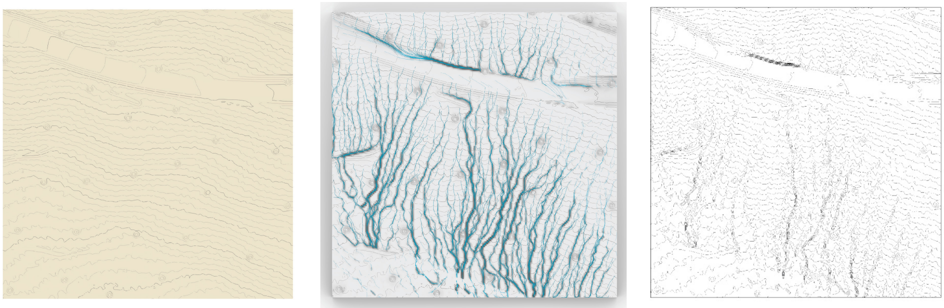

Fig. 4: Rosedale site data with applied erosion simulation, including key erosion and deposition paths, and the impact of observed obstacles and site-observed ground conditions

4 Discussion

The resulting model combines a cleaned, photogrammetric terrain model collected on site, with a scalable yet detailed simulation of rill-model erosion. This can form the basis for site selection, risk analysis, or developing of erosion mitigation strategies in high-risk areas.

The various data elements produced during the described process consists of base data and site analysis, as well as simulation data, such as the resulting flow-paths, erosion / deposition patterns and debris transport lines. The results reinforced the individual and combined roles that terrain roughness, converging slope details, and obstacles such as trees, fallen tree trunks, and rocks play in the resulting site-specific example. Site observation reflected the general trends of the erosion model; however, additional calibration can be applied to further refine the exact volume of material transported. The nature of the site material, being a mixture of fine ash, partially fire-consumed debris and dry topsoil that are non-uniformly distributed on the terrain lead to a model in which exact depths and volumes of material erosion and deposition are variable. Therefore, the erosion paths and patterns can be shown to have a higher fidelity than the depth of erosion. As referred to in the conclusion section, additional material-specific experimentation or specialist data would help to refine these models.

The potential for iteration in this process, both as a computational tool in simulation, and a workflow for gradually improving and refining the model worked well, especially given the responsiveness of the algorithm. The proposed additional applications for iterative design proposals using the same process are feasible in both implementation and viable design method.

5 Conclusion and Outlook

The relevance and importance of erosion simulation, and its challenges within the design disciplines are established, and the case is made for its viability and implementation. The lack of a designer-level toolset to deal with these issues has been addressed in this research, as well as the potential of these techniques for the AEC professions. The range of further applications and possible sites is only increasing with the growing impacts of climate change. Such simulation techniques can be deployed to predict erosion issues that may occur in the future and allow for pre-emptive interventions that may avoid or transform such erosion events into more positive outcomes. Within the space of fire events alone, there is a huge scope for adjusting landscape management practices to better recover from fire events, especially their implications for soils, sediment, and the fostering of their landscape biodiversity (TULAU et al. 2015, ATKINSON et al. 2020).

The imitation of real-world site conditions and recorded erosion sites are of key importance to further refine the plugin settings based on local conditions and the predictive accuracy and usefulness of the technique. Similar optimisation tools such as RAMMS have also been carried out both during and after the release of landslide and rockfall computational simulation (CHRISTEN et al. 2012).

Further development is required to optimize and better simulate existing high-resolution simulation models, as well as the integration of these techniques into teaching, research, and practice (IGWE et al. 2017). There is a strong potential for generating data layers for other applications and GIS systems and facilitating new forms of engagement and multidisciplinary collaboration in landscape engineering, remediation, and management projects. Where erosion can be predicted and mitigated, the potential for design with erosion processes emerges. The possibilities of hybrid design processes that work hand in hand with the environment, (GIROT & HURKXKENS 2018) open areas of potential design endeavour, in which the landscape can be shaped over time with minimal intervention and resources.

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