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Informing Topology: Performative Landscapes with Rapid Mass Movement Simulation

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Abstract: Designing with natural processes such as erosion and sedimentation has been problematic for practitioners from the design fields. In general, they lack the design expertise and tools necessary to readily achieve equilibrium in morphological and hydrological systems. In the context of natural hazards and continuing deterioration of local soils (MONTGOMERY 2012), an informed response to this challenge is necessary in order for designers to take advantage of the advent autonomous earth moving equipment (JUD et al. 2017) to achieve sustainable landscapes. We propose a design workflow where simulations of natural systems are inherently linked to the digital modelling environments of the designer. By connecting geotechnical and hydrological simulation packages to innovative 3D modelling tools, an iterative design methodology between digital construction processes and natural processes becomes possible. This prepares the ground for an informed and scientific design and construction method in landscape architecture.

Keywords: Simulation, algorithmic design, analysis, landscape topology, digital fabrication

1 Introduction

With the ever increasing pressure on alpine ecological systems (STOFFEL et al. 2014), working with local soil is one of the most effective strategies for a sustainable landscape future. The act of shaping terrain, mostly in relation to hydrological and infrastructural engineering, becomes a necessity in creating and maintaining a landscape that performs both on a technical (normative) and cultural level. However, if we want to open geotechnical engineering to landscape designers, actionable knowledge in dynamic natural systems is essential. In a collaboration between the Chair of Christophe Girot and the Chair of Gramazio Kohler Research at the ETH Zurich, with the support of the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL), two design studio have been carried out to investigate a sustainable landscape topology in the alpine regions of Switzerland. The studios studied natural and mechanical movements of granular material to ensure a long-term vision for a sustainable alpine environment. In the studios, topology was understood as defined by GIROT et al. (2013): not only are the surface features of a particular terrain described, but attention is also given to the morphologic, cultural and aesthetic dimensions of a landscape. In this case, this entailed the re-design of channelled alpine rivers flowing over debris cones on largely agricultural valley floors while permitting landscape recreation and leisure for the surrounding villages. Designing landscape resiliency against flood and debris flows was achieved solely by local topographic interventions with an ever changing baseline due to erosion and deposition processes within the perimeter. This way, the studios aimed to respond effectively to ongoing natural processes and recurring natural disasters, particularly debris flows and floods, without resorting to large and static concrete structures that break the connectivity of the natural landscape. Experimental landscape interventions using autonomous hydraulic equipment were used to

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continuously respond to – and redesign – topographic configurations with existing and newly deposited local materials (sand, gravel, rocks and residual materials).

To link the natural processes to the design proposals, rapid mass movement simulations were used to understand the evolving topography. Mass movement simulations are generally applied to inform local hazard maps and to test the affected area in case of extreme debris flows or landslide events. The results are then used for landscape planning and safety regulation. However, they can also become an extremely informative design tool when used during the design phases. In our case, it allowed us to take in any digital elevation model and simulate the flow of debris over its surface. Since there is still no universal program to design freely and intuitively with processes of erosion, transport, and deposition of material (LENZHOLZER et al. 2013), the design process was structured in iterative fashion between the simulation software and computational terrain modelling. This enables designers to understand the mechanisms of material movement throughout the design phases. In the following chapter we outline the digital design workflow that connect simulations of natural processes with computational terrain modelling.

2 Design Workflow

2.1 Simulating Natural Processes

Natural morphological processes (landslides, debris flows, erosion etc.) are difficult to understand or anticipate. General rules of erosion or deposition rates do not provide any specificity when designing with local site conditions. However, these processes are essential to control when designing new topographic solutions. Dynamic processes that change over time should be visualized with every design iteration to comprehend and control the performance of a landscape. We implemented a simulation workflow that not only simulates a final static state, but one that evolves iteratively to predict future events. In this way, the designer can refine the procedural design, anticipate its evolution over many years and test its resiliency. An intuitive and simple operation of the software is therefore key to a productive and precise design process.

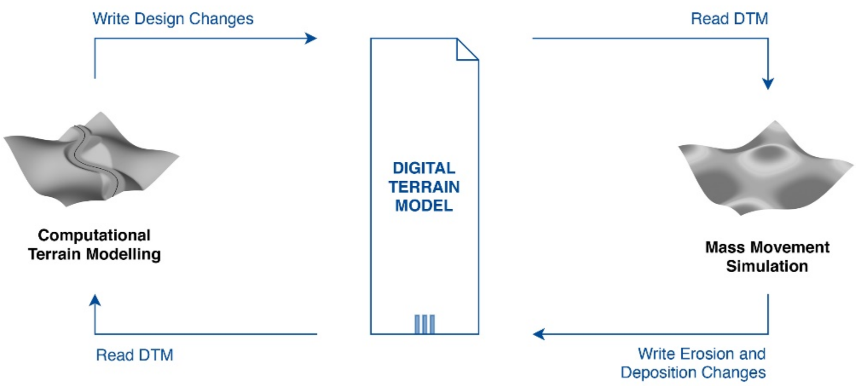

Fig. 1: Data flow diagram between the Computational Terrain Modelling Plugin for Rhinoceros 3D and the Rapid Mass Movement Simulation Software RAMMS

The proposed programming interface is able to communicate to both the simulation and the design modelling software. This was developed in collaboration with the WSL using rapid mass movement simulation software RAMMS (CHRISTEN et al. 2012). The simulation software handles all the soil friction parameters to accurately predict erosion, transport and sedimentation of debris flows. In addition to earth mechanical knowledge, the RAMMS software requires a topographic model of the design and parameters for the hazard events to be tested (in this case avalanches, rock falls or debris flows). The parameters are set in advance, ideally in close collaboration with an expert from the WSL. The digital terrain model can now be created from various data sources: in our case LIDAR was processed with additional terrestrial laser scanner data into a rasterized DTM with a resolution of one meter. These conversions were performed with open source geospatial library GDAL and the handy open source 3D point cloud and mesh processing software CloudCompare. From here, the digital modelling environment can be set up using Docofossor, a computational terrain modelling tool for Rhinoceros 3D developed by Ilmar Hurkxkens and Mathias Bernhard (HURKXKENS & BERNHARD 2019). This plugin provides a set of tools that enables the application of computational strategies on large scale digital terrain models. The final link between the simulation software and the design environment is made using the open ASCII Raster File format that both software's use to read and write digital terrain data.

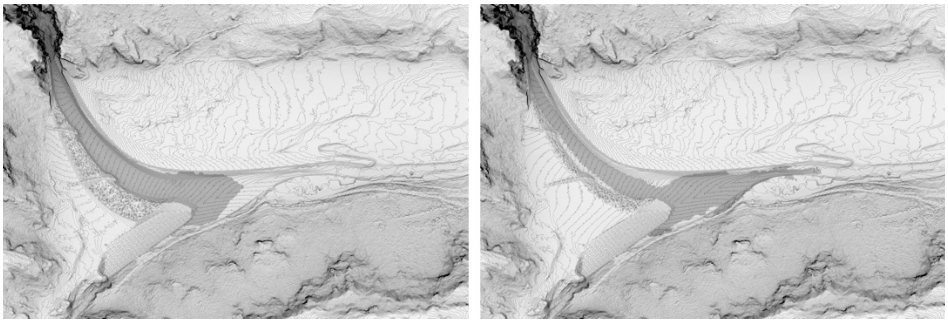

Fig. 2: Consecutive topographic models from the design studio showing the development of the terrain in year 5 and year 10 after the debris flows have deposited 150'000 m^3 of granular material on site. Material deposition is shown in dark grey after a debris flow event on top of the input topography. By students Elizabeth Levy and Stanislaw Modrzyk.

2.2 Iterative Terrain Modelling

Designs development is achieved in Docofossor with Grasshopper and Rhinoceros 3D using parameterized topographies to be able to react fast and efficiently to changes in the simulation outcomes. The plugin allows for various construction principles to be adapted dynamically like slope angles, volume calculations and surface roughness (for a full description of Docofossor see HURKXKENS & BERNHARD 2019). Now, in an iterative fashion, the DTM can be updated with new design interventions and serving as the basis for the simulations. After the simulation is done, erosion and deposition cubature's are computed to the DTM and read by Docofossor. This plugin in combination with RAMMS allows the terrain modelling, simulation and also visualization to happen in rapid succession. It becomes possible to generate first results within an hour after the various parameters relating to mass weight, friction values and duration of events of debris flows are set. As a result, information from the simulation is used to continuously adapt the design and create a landscape topology that can be valued on hazard remediation as well as on its landscape architectural qualities. The pre-set of a parametric approach allowed for quick changes to be made during the design phase. This is essential since topographic modelling tends to be a long and arduous task (WALLISS & RAHMANN 2016).

The advantage of this digital workflow also enables a direct instruction to autonomous earth moving equipment, and prepares the design workflow for evolving insights during construction (for instance, when sensors find the soil to be denser, wetter, or coarser, automatic adjustment could be made to the design). A dynamic construction process with evolutionary design development can therefore adjust to the inevitable changes over time. This becomes a fundamental prerequisite for future landscape design that must act responsibly and adaptively to evolving natural systems in times of climate change.

Fig. 3: Left: The alpine village Bondo in Canton Grisons after the debris flow of summer 2017. Large parts of the village were covered and infrastructure destroyed by this natural hazard. Right: Flooding of the Guerbe River in summer of 1990. Due to unexpected heavy rainfall the existing concrete check dams could not withstand the debris flows nor hold large amounts of water.

3 Experimental Design Studio

As part of a comprehensive research project on the design and control of an autonomous excavator, several design studios were initiated at the ETH Zurich as a collaboration between the Chair of Landscape Architecture of Professor Christophe Girot and Gramazio Kohler Research for Bachelor and Master students of the Faculty of Architecture. The last two studio took on large scale topographic design within natural environments: from a landslide catchment basin to the activation of an alluvial fan to create controlled deposits of eroded rock. In both cases, the complex interplay of topography with natural phenomena of soil and water movements was researched. The students were provided with the tools and workflow described above, which enabled them to evaluate their designs on morphological performance. The framework of the design studios limited the students to the use of local materials to foster sustainable material cycles and site-specific design approaches. The software RAMMS described in this paper was used for simulations of deposition and erosion. The graphical output of these simulations played a central role in the students' argumentation for design concept and configuration throughout the semesters.

The introduction to the simulation software and modelling software was quickly understood and used by the students. With the support of a tutor, and within a few hours, iterative optimization of the designs was achieved. The stepwise optimization was also part of the design task: on the one hand, the students were to design the processes of deposition and erosion according to their own ideas per single event (debris flows, landslide), on the other hand, they were supposed to simulate several loops of topographic transformations one after the other. Therefore, the design site transformed "naturally" by the means of material erosion and deposition. This transformation was then integrated into every consecutive simulation to design a continuing procedural approach to erosion and deposition instead of a single static landscape.

The first studio in fall 2018 studied the village Bondo in the Swiss Canton Grisons where a chain of major tectonic events has deeply affected the landscape and required urgent remedial measures. Heavy rainfall will result in further landslides, worsening the precarious situation in the coming years. In response to the challenges posed by the disaster, the studio asked students to develop new topographic solutions only using sand, gravel and rock from the landslide. For this site, the simulation showed that it was possible to divert the material around a village and further downstream with simple topographic modulations. This meant no static concrete measures would have to be taken on site. By locally shifting the granular material, the topology was able to catch, resist and divert the landslides while creating a new leisure area for the inhabitants.

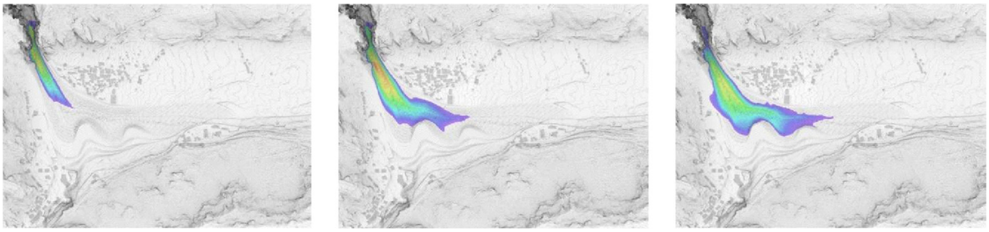

Fig. 4: Material movement during a simulated debris flow in three different time steps with RAMMS by students Andrea Colzolar, Sam Mettraux and Carlo Molteni. The topographical intervention of this design leads to a redirection of the material flow, thus avoiding the neighbouring village.

The second studio took place on the alpine river Guerbe in Canton Bern. Despite the channelling of the river and the construction of 160 check dams, flood damages could not be avoided and still today hydraulic protection measures are carried out without success. Instead of concrete and static solutions, the studio explored a new topology made from only sand, gravel and rocks. The task was to redesign the alluvial fan of the river to intercept and store large amounts of eroded material before it would lead further downstream to destruction, blockages and subsequent flooding. It became clear that a direct manipulation of the bed was able to slow down and stop the expected debris flows within the set perimeter. Simulations with RAMMS demonstrated that scales and amplitude of the objects in the bed have a big influence on where the material would deposit. However, continuous re-distribution of material was necessary as the debris flow would fill up the river bed within a few years. Because of this, students applied advanced autonomous construction methods to maintain a safe environment for the surrounding villages and farmers.

The designed interventions showed how topography might be able to replace conventional check dams or other static infrastructure that is difficult and/or expensive to maintain. The interdependency between autonomous hydraulic intervention, natural processes and design intention became critical to every design proposal. By using simulation in the early design phases, students could quickly sketch out their topographic strategy. This would have been very hard to achieve using conventional tools or basing design decisions solely on acquired knowledge or expertise. As it turned out, natural processes are hard to predict accurately by experience and intuition alone.

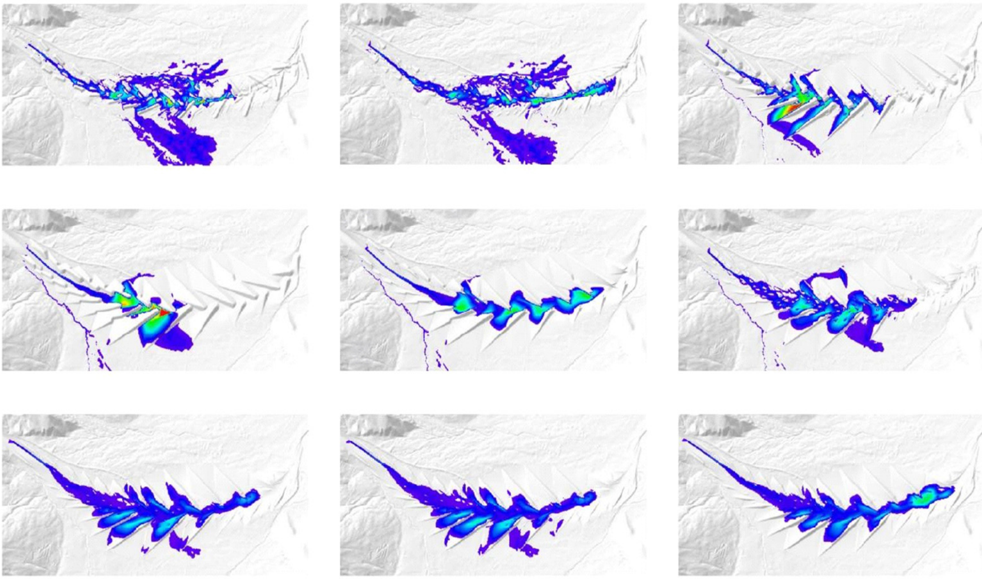

Fig. 5: Nine simulations – left to right, top to bottom – in order of design development of a debris flows with a volume of 50’000 m^3. Simulations made with RAMMS by students Caspar Trueb and Lorin Wiedemeier. All nine simulations were created by the same team of students during the second experimental semester. They show in different colours from violet (low flow height) to red (maximum flow height) the final depositional state of the debris flows. Clearly visible is the ongoing refinement of the design proposals were the debris flow exits it bed in the early stages but becomes more and more managed towards the end. Often only small topographic changes resulted in a very different affected area map and flow direction.

4 Conclusion

Simulation software for natural processes has been reserved for specialists in their respective fields and are only able to deal with a fraction of the questions regarding a particular design. The challenge for the designer is to combine the information from many specialists into a concrete design proposal. Verifying any solution with simulations currently means a slow coordinated effort with the various experts. In particular, the operation of the software is almost impossible without explicit expert knowledge and is not very profitable for designers in most cases. In order to base future drafts to a greater extent on expert knowledge, an interdisciplinary approach appears to be more promising where specialists work closely with designers in order to precisely assess their needs and requirements. The expertise gained can then be integrated into the design process. Particular attention must be paid to the iterative nature of the design. Ideally, simulations and site conditions are parameterized and can therefore be repeated and remodelled at will. At present, neither the education of designers nor the design software's are equipped for topographic design that is informed by natural processes acting on it. A close integration between simulation software and design tools is therefore needed to embed morphological and hydrological processes effectively into sustainable and resilient design proposals. Complex and interesting design tasks will otherwise fall increasingly into the domain of specialists.

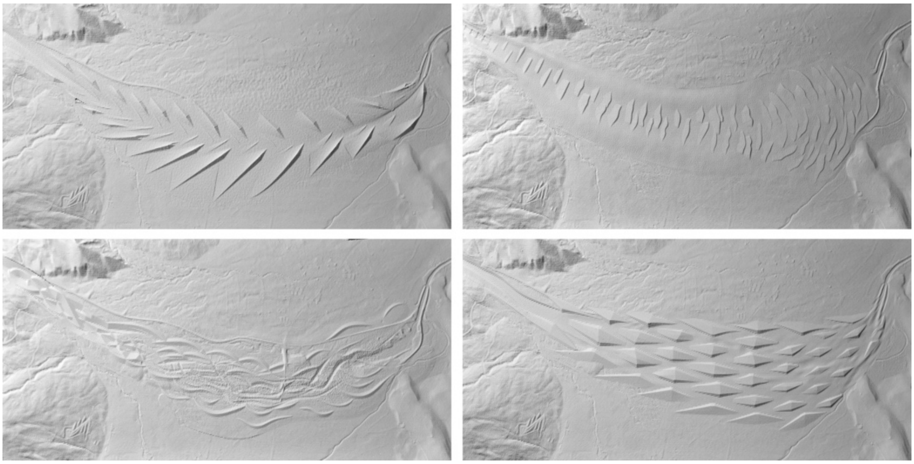

Fig. 6: CNC Models from the second design studio "Robotic Landscapes" illustrating the landscape after 20 years of natural and mechanical earth movements. The landscape topology is expressed as an open and accessible leisure area, opposed to the channelled and dammed river that existed here before the design intervention.

In addition to the topographic modelling and simulation workflow discussed in this paper, we see opportunities for an even tighter integration. The findings from the experimental design studios show huge potential for a seamless feedback loop between simulation and 3D modelling. Further development should incorporate simulations of material transport by water and possibly integrate other natural and anthropogenic factors as well. Open source solutions and innovative programming interfaces that integrate specific expert knowledge are essential to fulfil future landscape challenges. An automated feedback loop becomes particularly interesting in combination with the targeted construction method where large-scale autonomous construction equipment will be able to perform maintenance tasks in the landscape (HURKXKENS et al. 2017). In order for surveying systems and intelligent construction machinery to react appropriately and meaningfully to the constantly changing topography, we must be able to take an educated look into the future. The above-mentioned simulations combined with on-site machine learning (CANTRELL & ZHANG 2018) would be able to predict future material movements and automatically adjust previously implemented topological strategies. While we still have a long way to go to realise this future, the work discussed in this paper demonstrates how design can be linked to the complexities of rapid mass movement and the inexorable changes of topographic configuration over time. It proposes a new equilibrium between natural processes and the construction of complex topographies through an informed design methodology. It enables designers to think and act in dynamic terrains, and in doing so building a resilient, sustainable, and adaptive landscape future.

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