

Hybrid Terrain Modeling: A Multidimensional Landscape Design Method

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Abstract: This paper focuses on how, in the wake of shifting hydro-topographic regimes in Switzerland, digital design methods can be combined with tactile modeling methods to support the overall design process and output. Bridging crucial gaps in the workflow from geodata to physical modeling the paper proposes a design process which iterates between the realms of the digital and the analog. This approach combines the precision and objectivity of geospatial data with the intuitive working modes and tactile interaction with materiality by introducing a custom Grasshopper plug-in. The paper presents methods tested by students of architecture and landscape architecture, allowing to show different levels of complexity within the method from the digital model to the physical and back to the digital for fully circular iterations.

Keywords: Hybrid design methods, hydro-topography, LiDAR Geodata, Rhino Grasshopper, 3D printing

1 Introduction

The shifting climatic circumstances and water cycles in Switzerland and beyond call for a shift in dealing with water flows, topography and the landscape in general (VOSER 2024). Landscape dynamics are becoming increasingly frequent and pronounced, creating a conflict with the predominantly static landscape infrastructures constructed over the past two centuries (BAN et al. 2020, JACQUEMART et al. 2024, SCHERRER et al. 2016). Over the past decades, engineering disciplines have been leading water management projects in Switzerland and across Europe. It could be argued that landscape architects and their more holistic view should once again assume a more central role in these works (SALLIOU et al. 2025). In order to achieve this, the role of the landscape architect needs to be reconsidered. We argue for a discipline empowered with the means and agency to deliver spaces that allow for natural dynamics whilst integrating social and ecological dimensions all founded on quantitative data. Salliou et al. note that digital models can improve the “hydro-socio-ecological” dialogue for water systems by allowing for precise digital modelling. As implicit in this wording an exclusive focus on digital data and computational methods, their prioritization of objectivity and precision can result in a detachment between the designer and the landscape to design (RAMIREZ & OLÓRIZ SANJUÁN 2016) or as Pallasmaa puts it: “Design is not merely a rational, technical and performative task” (PALLASMAA 1996). Digital tools are most effective when combined with complementary methods and their intended use made explicit (FRICKER et al. 2013, 2024). As other studies show digital-physical combinations can lead to successful design processes if used to their specific advancement (HARMON et al. 2016). This paper will make a case for design methods on the fringes of the digital and the haptic.

2 A Method for Hybrid Design

2.1 Related Works

We propose a hybrid design approach that combines digital and physical modelling methods – allowing for effective translations between multiple forms of representation, model interaction and design methods. Building on prior tangible-digital terrain studies and Rhino-based hydro-analysis, our contribution refines the balance between precision and iteration speed, allowing for meaningful geometric fidelity and rapid iterations. Both being essential when addressing the challenges of designing dynamic, evolving landscapes. The work relates to studies of AR-Sandboxes (HERMANSDORFER et al. 2020) or the Sedimaschine (CANTRELL & HOLZMAN 2014) which provide live feedback at relatively low fidelity as well as to studies on rapid prototyping with Sand (ROBINSON 2014) or CNC Milling (GIROT et al. 2010) which allow high fidelity but require time-intensive iteration loops and extended technical knowledge. In comparison our method is characterized by a low-entry barrier and haptic modelling techniques. Basing our method on the raw LiDAR data, not relying on translations to rasterized or vectorized data, continues a culture of “Cloudism” (GIROT 2018). Against this backdrop, we ask: How can low-barrier workflows leverage high-resolution geodata, interoperate with existing tools, and be combined with tactile terrain modeling methods to support early-stage topographic and hydrologic landscape design? What benefits and trade-offs do such a workflow entail, particularly in geometric precision, iteration speed, time investment, and the ability to explore design variants, while enabling an intuitive, multisensory engagement with terrain?

2.2 Geodata as a Basis

In a time where hydraulic amplitudes are increasingly shaping landscape design decisions, basing any design on objective georeferenced data is gaining greater importance. The Federal Office of Topography (Swisstopo) has been using LiDAR technology for creating topographic models (DTM) for the past 25 years but only since 2025, high-resolution geodata (classified point clouds with at least 5 points/m², on average around 15-20 points/m², positional accuracy: ±20 cm, vertical accuracy: ±10 cm) have been made available across the entire territory of Switzerland (SWISSTOPO 2025). Despite the challenging topography, the dataset has one of the highest nationwide precisions in Europe (KAKOULAKI et al. 2021). Datasets as point clouds and their subsequent products like rasterized DEM/DTM or vectorized building datasets have become a standard for open government data in Switzerland and beyond. The uninterrupted coverage, high accuracy, and resolution enable designs to be based on geodata at all locations and even at small scales. Data from GIS-platforms such as Swisstopo in Switzerland come in specific formats, which are not directly compatible with design software in landscape architecture and often require various levels of translation before being interoperable. Even though efforts have been made to standardize national geodata across Europe, different formats continue to exist (KAKOULAKI et al. 2021). The three key issues are (1) the translation between different data structures: 3D point data, vector formats, mesh surface or solids, (2) the conversion of a given reference coordinate system to a local origin point and (3) the management of large volume datasets.

2.3 An Accessible Iterative Approach

To establish a design method capable of dealing with today's challenges of hydraulic shifts, we propose a hybrid approach that unites the precision and objectivity of digital data with tactile, hands-on methodologies. The method therefore asks for workflows from geodata to physical models which, due to the mentioned challenges of differing data structures, data volumes and georeference, require advanced software or programming skills by the designer and are not suitable for iterative loops. We introduce a low-barrier, closed digital-physical-digital workflow, operationalized with a specifically developed Grasshopper plug-in (MURMELI 2025) that natively ingests national LiDAR data, 3D-prints negative formworks, enabling rapid sand/clay re-casting (5-10 min/variant) and re-scans for quantitative hydro-topographic analysis, supporting early-stage landscape design and teaching at scale (Fig. 1).

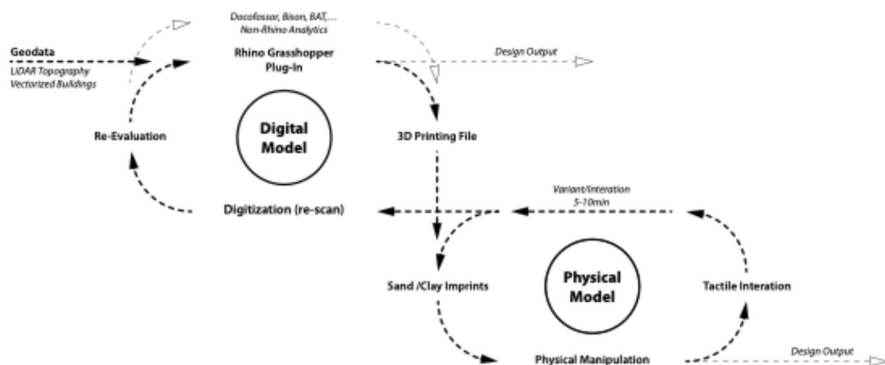


Fig. 1: Method Diagram (digital-physical-digital Workflow) (Image Credits by the Authors)

The custom Grasshopper plug-in was specifically developed to bridge these technical gaps and allows for rethinking hybrid design iteration processes. The components consist of four categories: Importers, Tools, Analysis and Exporters. (Fig. 2) Specific import nodes are programmed to import .las, .laz and .xyz LiDAR files as well as .dxf vector-files utilizing Python 2 for Rhino 7, Ironpython and Python 3 for Rhino 8. The importers include point sampling and classification filters. This increases import efficiency and allows for larger datasets to be imported in both small or large scales.



Fig. 2: Toolbar Rhino Grasshopper plug-in (MURMELI 2025)

The importers allow for bringing the public data into Rhinoceros and leverage existing tools like Docofosser (HURKXKENS & BERNHARD 2019), Bison (BISON 2018), BAT (MA 2024) and many more to investigate watersheds, water runoff or other hydro-topographic characteristics. For the specific workflow of 3D printing custom tools (section 2) were programmed: Point combiner, Point thinner, Shift, Local Z-max, Local Z-min as well as an interface to docofosser's specific distance field format. For topographic and hydrologic analysis section 3 provides eight widely used analyses natively in the plug-in. Further a custom exporter for .stl-files is provided to complete workflows for 3D printing. In combination with standard Grasshopper components the developed plugin supports workflows from geodata download to 3D print file exports. The plug-in is conceived as open access and can be continuously extended with specific tools based on emerging needs during design applications.

3 Design Iterations between the Physical and the Digital

In the following design applications, the models were printed with PLA filament both as positives as well as negative formworks. The latter allows for casting the positive topography creating pressed sand or clay models, which later can be physically manipulated. It allows for conceptual models in large scales and manual sketching in the physical model as well as more detailed hydro-topographic investigations in smaller scales. A new imprint of a sand model with an existing formwork is possible within five to ten minutes which makes it possible to not only work iteratively but also in variants, exploring different time scales, erosion processes and hydrological variabilities. This massively decreases physical model making times and creates repeatable precise outputs. 3D printers with PLA filament commonly have a resolution of ~ 0.2 mm in height and this precision is replicated on the sand imprints, allowing for details of up to 5 m in models of 1:25'000 and accordingly up to 20 cm in the scale of 1:1'000 or 10 cm in 1:500. (Fig. 3.1) The method was applied in a graduate design studio in landscape architecture (Spring 2025) and undergraduate design studio in architecture (Fall 2025) at the ETH Zurich. In the architecture program, more than 300 students were introduced to topography and hydrology through this method of hybrid modelling, whereas in the landscape architecture program, discourse and form-finding processes using both digital and physical modelling techniques were explored in greater depth allowing for more complex design processes.

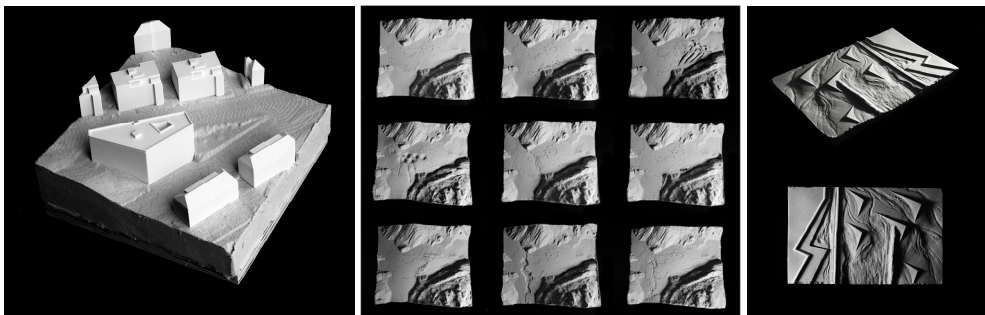


Fig. 3: Left: Inner City Model 1:500 by Lorethan N.; Middle: Concept Models 1:25'000, collective student works; Right: Flow Channels 1:200 by T.-W. Chen & Y. Hou

Starting with large scale conceptual models, the method allowed to sketch even unscaled design ideas (Fig. 3.2). Later smaller scales and more precise intervention modelling, manually shaping the model and digitally deforming the topography before printing a model (Fig. 3.3). The back and forth between digital and physical interventions requires rescanning physical models and juxtaposing the original topography and the manually shaped models. To do so, different strategies were chosen to digitize the physical models. These included laser scanning (GOM Scanner, Artec Leo), photogrammetry and depth-cameras. The latter lacked precision, while hand-held scanners and image-based photogrammetry became the preferable methods. Using these techniques, manual work can be re-evaluated through digital analysis like slope orientation or steepness, water runoff or earthwork volumes (Fig. 4.1, Fig. 4.2). A full end-to-end cycle (3D-printed formwork from geodata, pressed sand-model, and rescanned with a GOM scanner) resulted in a standard deviation of $\pm 0.1654\text{mm}$ in the 1:3000 scale model, equivalent to $\pm 0.4962\text{m}$ at full scale (Fig. 4.3). Models in scales of 1:1000 or larger have an equivalent real-world error of $\pm 0.2\text{m}$ and less, which is comparable to the vertical precision of the source geodata.

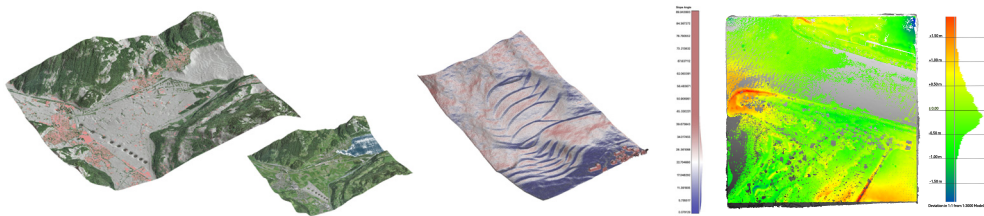


Fig. 4: Left: Mixed Models: rescanned physical Model juxtaposed with digital LiDAR Model, Scale 1:25'000, Design Studio 2025; Middle: Slope Steepness Analysis on rescanned physical Model, Scale 1:1'000, by Lang A., Lepori L.; Right: Deviation Analysis after full circle process: geodata/physical model/re-digitization with a standard deviation of $\pm 0.1654\text{mm}$ at a scale of 1:3'000

4 Discussion and Conclusions

Overall, the project shows how condensed workflows in combination with the developed Rhino Grasshopper plug-in allow for design processes with quicker physical modelling that supports more iterative design loops. The proposed method differentiates itself with higher accuracy than other methods due to a haptic focus like tangible tables that allows for more physical interaction and quicker iterations than other precise modelling methods like CNC milling. Despite this carefully tuned balance between precision, haptic experience and time investment, limitations to the methods became apparent during the design applications. 3D printer dimensions limit the size of the model size unless the model is divided and reconfigured into multiple tiles (Fig. 5.3). Initial 3D printing times can reach 10 hours and more per model (25 cm x 25 cm). Consequently, the method is particularly beneficial when existing formwork can be used repeatedly for variants, iterations or group works. The manual intervention has some limitations. Even though providing for characteristic geometries and the haptic experience of the designer manual techniques have limitations in resolution and precision. Especially at large scales, manual modelling is limited to conceptual schemes and exaggerated features. In terms of materiality, the case studies have used kinetic sand, clay

and plaster for their possibility to work on manually. An interesting next step could be to work with site specific material mixtures. Throughout the case studies it became apparent that the presence and the workings of a given topography have much more impact on the design process when physically present in space. Manual manipulation, even if conceptual or out of scale enhances the interaction with the topography. The case study with the more advanced students showed that the back and forth from a digital to an analog realm provides a more multifaceted insight and understanding and allows combining digital analysis tools while circumnavigating the rigidity of purely computational design methods. By breaking these rigid frameworks through unintentional and intuitive modelling, a productive tension between the precise and the intuitive emerges and is revealed in the juxtapositions.

In summary, the method proved to have many applications from early-stage design to final representational models. Allowing students to design in the physical model while keeping efficient work iterations both for advanced master students in landscape architecture as well as previously untrained students of architecture suggests a wide pallet of applications for different stakeholder groups and proficiency levels. Such design processes can lead to better insights in site-specific topographies, faster understanding and communication of topographic and hydrologic specificities as well as more freedom in designing “by hand”. While remaining connected to the precision of geodata, the methods engage the designer directly with materiality, connecting them back to the physicality of landscape and allowing, in Pallasmaa’s words, the use of “[...] *our magnificent, multisensory, simultaneous and synchronic capacities of imagination*” (PALLASMAA 1996, 5). This allows users to not only address today’s hydro-topographic challenges with digital tools, but also through tangible imaginations and physical variants of changing topographies.

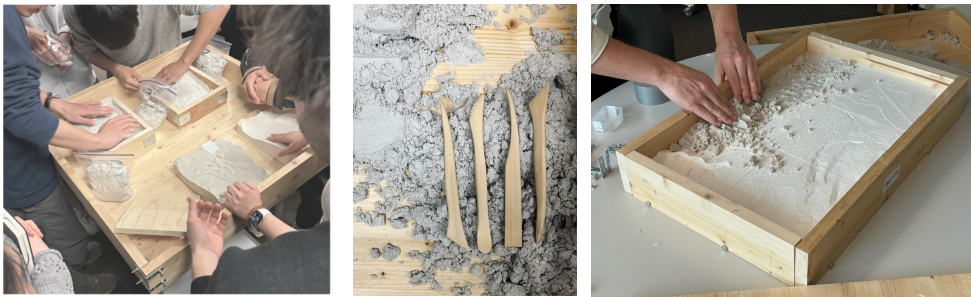


Fig. 5: Left: Students working by hand, Spring Semester 2025; Middle: Tools for manual modelling; Right: Multiple tiles combined to one formwork – sand model pressing (Image Credits: Silvia Converso and the Authors)

5 Acknowledgement

The case studies and their results wouldn’t have been possible without the help of the entire teaching team, namely Coralie Berchtold, Bea Kisler, Nathan Lorethan, Dylan Tori, and Martin Zwahlen and the many students applying the tools to their project work, embracing the methodological experimentation. For python scripting in the Grasshopper plug-in and for spelling and grammar correction in this paper artificial intelligence was utilized (OPENAI 2025).

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