1 Tangible interfaces for Geographic Information Systems

Coupling physical models with GIS In a seminal paper Ishii and Ullmer envisioned tangible user interfaces that would 'bridge the gap between cyberspace and the physical environment by making digital information (bits) tangible' (1997). They described 'tangible bits' as 'the coupling of bits with graspable physical objects' (Ishii and Ullmer, 1997). Tangible interfaces like Urp (Underkoffler and Ishii, 1999), Illuminating Clay (Piper et al., 2002), and SandScape (Ratti et al., 2004) enriched physical models of urban spaces and landscapes with spatial analyses and simulations like wind direction, cast shadow, slope, aspect, curvature, and water direction in order to enhance and streamline design processes. Many of the analyses used in Illuminating Clay were adapted from GRASS GIS (Piper et al., 2002). and eventually Illuminating Clay was coupled with GRASS GIS to draw on its extensive libraries for spatial computation. The aim of coupling Illuminating Clay with GRASS GIS was to 'explore relationships that occur between different terrains, the physical parameters of terrains, and the landscape processes that occur in these terrains' (Mitasova et al., 2006). This research to couple a physical landscape model with GRASS GIS led to the development of the Tangible Geospatial Modeling System (Tateosian et al., 2010) and Tangible Landscape (Petrasova et al., 2014, 2015).

There are many reasons for coupling a physical model with a GIS – for developing a tangible interface for a GIS. The tangible interface enables intuitive digital sculpting, streamlines design processes by seamlessly integrating analog and digital workflows, and improves collaboration and communication by enabling multiple users to simultaneously interact in a natural way (Ratti et al., 2004). The GIS provides the extensive libraries for geospatial databasing, processing, analysis, modeling, simulation, and visualization needed to address real world problems (Tateosian et al., 2010). A tangible interface for a GIS that enables intuitive digital sculpting while providing analytical or simulated feedback would allow users to dynamically explore how topographic form influences landscape processes (Mitasova et al., 2006).

To couple a physical model with a GIS the physical model needs to be digitized and imported into the GIS and then models, analyses, and simulations need to be output as feedback. Once a physical model has been 3D scanned as a point cloud it can be imported into GIS. GIS functionality for handling tangible input could include georeferencing, point cloud processing and importing, binning or interpolation, and object detection. Once the tangible input has been imported into GIS it can be used in geospatial models, analyses, and simulations. GIS have extensive libraries for geospatial modeling, analysis, and simulation including statistical analysis, terrain modeling, terrain analysis (including slope, aspect, curvature, and landform recognition), cut-fill analysis, volumetric modeling, time series analysis, solar irradiation modeling, hydrological modeling, water flow simulation, sediment flow and erosion simulation, landscape fragmentation analysis, landscape change modeling, least cost path analysis, and network analysis and optimization. These libraries support landscape planning applications including stormwater management, flood control, landscape management and erosion control, trail planning, viewshed analysis and visual impact assessment, and the assessment of solar potential. They also support landscape change applications including wildfire management, disease spread management, urban growth, and sea level rise adaption. GIS also have libraries for visualization including 2D and 3D cartographic rendering, graphs, and animation that enable graphical feedback.

Challenges and future work Theoretically Tangible Landscape should enable natural and collaborative interaction with a GIS by coupling physical and digital geospatial models. Natural interaction with geospatial models should enhance spatial cognition and encourage spatial learning. This should be empirically tested in experiments and case studies so that we can critique and develop the theory grounding Tangible Landscape, identify cognitive challenges, and improve the design.

Tangible Landscape's physical model, augmented with projected graphics, only affords a bird's eye view of the modeled landscape. With a bird's eye view of a scale model one can not get a sense of how the landscape would look when one is there. While 3D renderings can show how the landscape would look from a viewpoint, immersive technologies could give a richer impression of the space. Virtual reality headsets with interactive 3D scenes could be integrated with Tangible Landscape so that users can explore and experience the modeled landscape at a human scale.

Tangible interfaces like Tangible Landscape have two feedback loops – there is passive, kinaesthetic feedback from grasping the physical model and active, graphical feedback from computation. This double interaction loop could be enriched by a third form of feedback, by computationally transforming the physical model for active, kinaesthetic feedback (Ishii, 2008). While there is ongoing research into actuated shape-changing displays like Relief (Leithinger and Ishii, 2010), they are expensive to build and maintain and the size of the actuators limits the spatial resolution making the surface discrete rather than continuous. I instead propose to integrate robotic fabrication technologies into Tangible Landscape in order to computationally transform the physical model with high precision. A robot mounted beside Tangible Landscape could precisely manufacture changes to the physical model using computer numerical control milling, 3D printing, and casting based on geospatial modeling and simulation. While it would take substantial time to fabricate new models using digital fabrication technologies, small changes could be made in near real-time.

Digital fabrication technologies could also couple Tangible Landscape with the real world landscape being modeling. Live, real-time data about the landscape could be collected and streamed from sources like UAV flights, lidar stations, monitoring stations, and embedded sensors. With this streaming data the robot mounted beside Tangible Landscape could automatically transform the physical model representing the landscape in near real-time response to changes in the landscape. This would give us a live, tangible representation of a landscape that could help us to understand its processes and support near real-time decision making. Tangible Landscape could also be integrated with digital fabrication in the field – with computationally driven, location-aware earthmovers – to directly transform the landscape being modeled.

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