Tangible Landscape: A Waterway Design Education Tool

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Abstract: This study proposes the specification of a Tangible landscape (TL) to be used in the educational setting of a landscape design atelier. The main learning outcomes are to design alternative waterways in a riverine area taking into consideration the impact of waterflow on the landscape as a result of the designed waterways. TL is a projection-augmented sandbox powered by a Geographical Information System (GIS) for real-time geospatial analysis and simulation by coupling a mock-up with a digital model in near-real time by using 3D sensing, enabling users to apply geospatial simulation and visualisation. Notwithstanding the proven qualities of using TL in an educational setting, some obvious topics are addressed regarding the role of TL in educating waterway design. These topics are; how to realize a reusable and semi-realistic mock-up, in what way could waterways be designed without disrupting the mock-up, and how to give appropriate feedback during the design of waterways regarding the impact of waterflow change. The specified TL includes a thread-based approach that enables the student to design without disrupting the mock-up. Besides near real-time iterative results – both visually and numeric – it shows the hydrologic impact of the designed waterway. The expected outcomes of the current TL in education may stimulate topological thinking and insight into riverine geomorphology, it fosters representative and integrative thinking because of the near real-time relation between the design (form, scale, size) decisions and hydrologic process impact which makes the impact of design decisions on hydrological processes more illustrative and tangible.

Keywords: Tangible User Interfaces, hydrological modelling, geospatial modelling, education, landscape architecture

1 Introduction

Tangible Landscape (TL) is a projection-augmented sandbox powered by a Geographical Information System (GIS) for real-time geospatial analysis and simulation (PETRASOVA et al. 2018). TL couples a mock-up with a digital model in near-real time by using 3D sensing, enabling users to apply geospatial modelling, simulation and visualisation. The visualized elevation data is altered by changing the mock-up. TL is an example of a Tangible User Interface (TUI). A TUI enables users to physically interact with the digital environment (ISHII & ULLMER 1997) by removing the need for interaction with a mouse and keyboard by shifting to manipulation by touch and feel. TL has proven to be an effective tool for accurately modelling topography, to shape ideas, to perform quantitatively testing and to use an iterative design process to model topography using a digital reference (HARMON et al. 2018). It increases the understanding of geomorphology, of damming on historical flood landscapes (RENGIFO 2018), the course of waterways (HARMON et al. 2016, WOODS et al. 2016), changing hydrological conditions (RAHMAN et al. 2017), and the understanding of the difference between real and abstract representations (JERMANN & DILLENBOURGH 2008). Using TL, waterways could be designed by providing near real-time analyses and feedback. We propose

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TL in the educational setting of a landscape design atelier of which the main learning outcomes are to design alternative waterways in a fluvial area taking into consideration the impact of waterflow as result of the designed waterways on the landscape. Notwithstanding the proven qualities of using TL in an educational setting, such an approach has not been applied. Regarding such a TL some specific topics were not yet addressed, (HARMON et al. 2016 and 2018, RENGIFO 2018, MILLAR et al. 2018, RAHMAN et al. 2017) which can be answered by the following research questions:

1) How to create a reusable and valid near-realistic elevation model which has not to be constructed after every design session within a design atelier?
2) What design tool will not disrupt the mock-up and does support shape and size characters of a waterway?
3) Which numeric and visual feedback mechanism will support waterway design with specific – numeric and visual- information regarding the waterflow impact?

2 Methodology

To create a near-realistic elevation model, a mock-up of the study area was created using magic sand and a mould. The mould of 100 x 75 cm was based on a national DTM. To create the mould, the elevation of the DTM was inverted to correctly model the topography of the resulting mock-up. The elevation of the DTM was exaggerated 8 times, increasing the height differences, making it more easily distinguishable by the human eye and the scanner. The mould was constructed using CNC routing. To create the mock-up, the mould was placed into a rectangular frame (Fig. 1). Magic sand was placed into the rectangular frame, on top of the mould, uniformly filling it to the top. A plate was fitted on top of the levelled sand bed. Next, the frame was flipped upside down. Finally, the plate and mould were removed to reveal the mock-up. The experimental set-up of TL is depicted in Figure 2.

To enable the reuse of the mock-up, a non-disruptive design approach was applied by using a thread to 'design' the new trajectory of a waterway. By doing so, several interventions were simulated without distorting the mock-up. As a trajectory only defined the length and shape of a waterway, a newly developed feedback mechanism was applied that computed and visualized the effect of an intervention on the hydrology for a given flow rate. The development of this mechanism was split up into two parts. First, the centre line of the proposed waterway was constructed (Fig. 3, steps 1-5). Second, a raster representing the waterway was constructed (Fig. 3, steps 6-10). Finally, parameters for design such as the length of the trajectory, wavelength, sinuosity and amplitude were calculated. Initially, the flow rate and composition of the sediment were defined as model inputs. DEN BERG (1995) found that these parameters – in combination with the valley gradient – determined the geometry of braided and meandering waterways.

Fig. 1:
The mould; an inverted DTM of the study area which was used to create the mock-up. Z-values were exaggerated 8 times

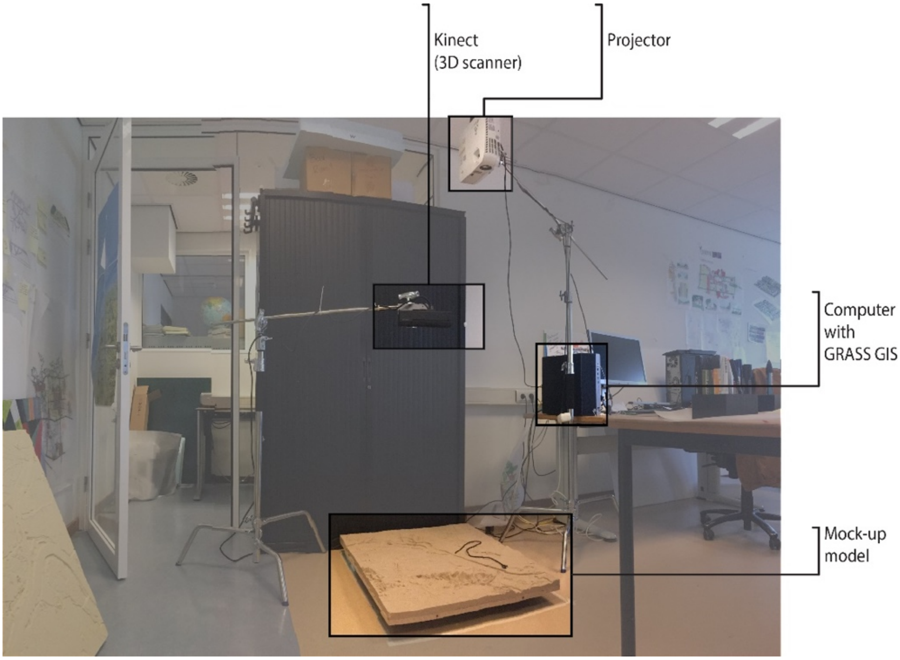

Fig. 2: Experimental set-up of Tangible Landscape at the *atelier* at *P4*. The hardware components: 3D scanner, projector, computer with GRASS GIS are depicted as well as the mock-up.

The geometry was predicted by using hydraulic-geometric equations (LEOPOLD & MADDOCK 1953) which relate the flow rate Q to a certain *width* and *depth*, according to following relations:

$$width = a * Q^b \tag{1}$$

$$depth = c * Q^f \tag{2}$$

with the coefficients a, c, and the exponents b, f being dependent on the type of river and climate. The hydraulic-geometric relations have been used for the design of waterways before with little variation in the exponents, for which in most cases $b = 0.5$ and $f = 0.4$ were used (MAKASKE & MAAS 2015). HOBO (2006) used a value of $a = 4.0$ and $c = 0.58$ for clayey banks in the study area.

To describe the shape of the proposed waterway a centre line was constructed. First, the raster cells representing the thread were filtered out (Fig. 3, step 2). A growing algorithm (LARSON 2019) was used to fill possible gaps. Next, a thinning algorithm was applied (Fig. 3, step 3) (JANG & CHIN 1990). The thinning algorithm used an iterative process, peeling off the outside pixels after each iteration. A cleaning algorithm was used (GERDES et al. 2016) (Fig. 3, step 5) to remove small spurs. Finally, the multiple vector lines were converted into a single polyline.

Using the constructed centre line, a waterway raster was constructed using the flow rate dependent width (Fig. 3, steps 6-7). Next, the depth of the design was calculated and integrated into the scanned DEM (Fig. 3, steps 8-10). The depth given by the hydraulic-geometric equation (Equation 2) indicated the depth of the waterway bed in relation to the top of the waterway, not the actual depth in relation to the scanned DEM. To calculate the actual depth more processing was needed (Fig. 3, step 8). Water flows from high to low elevation following the valley gradient. To simulate this, a raster plane was constructed according the valley gradient, length of the river, and aspect. The gradient was calculated as; $valley\ gradient = 180/(\pi * arctan2(\Delta h/\Delta d))$ where Δd is the Euclidean distance and Δh the height difference. The Euclidean distance, Δd, was calculated using the Pythagorean formula. Then, the aspect was calculated as $aspect = 180/(\pi * arctan2(\Delta x/\Delta y))$ where Δx and Δy are the differences between respectively the distinctive x-coordinates and y-coordinates.

From this raster plane the depth calculated by the hydraulic-geometric equation (Equation 2) was subtracted to derive the actual depth of the waterway (Fig. 3, step 9). Using the previously calculated waterway raster as a mask, the calculated gradient raster with the designed depth was re-sampled. A composite raster was created by patching the scanned DEM and the re-sampled waterway raster Fig. 3, step 10). Finally, this composite raster was projected on top of the mock-up.

Design parameters were calculated for each iteration. A schematic overview is depicted in Figure 4. Wavelength and amplitude (LEOPOLD & WOLMAN 1960) were calculated according to Equation 3 and Equation 4, respectively:

$$wavelength = 11 * w^{1.01} \tag{3}$$

$$amplitude = 3.0 * w^{1.1} \tag{4}$$

With w denoting the width of the river. The hydraulic radius, which can be used as a good estimation for the depth for design (MAKASKE & MAAS 2015) is described as (BROWNLIE 1983):

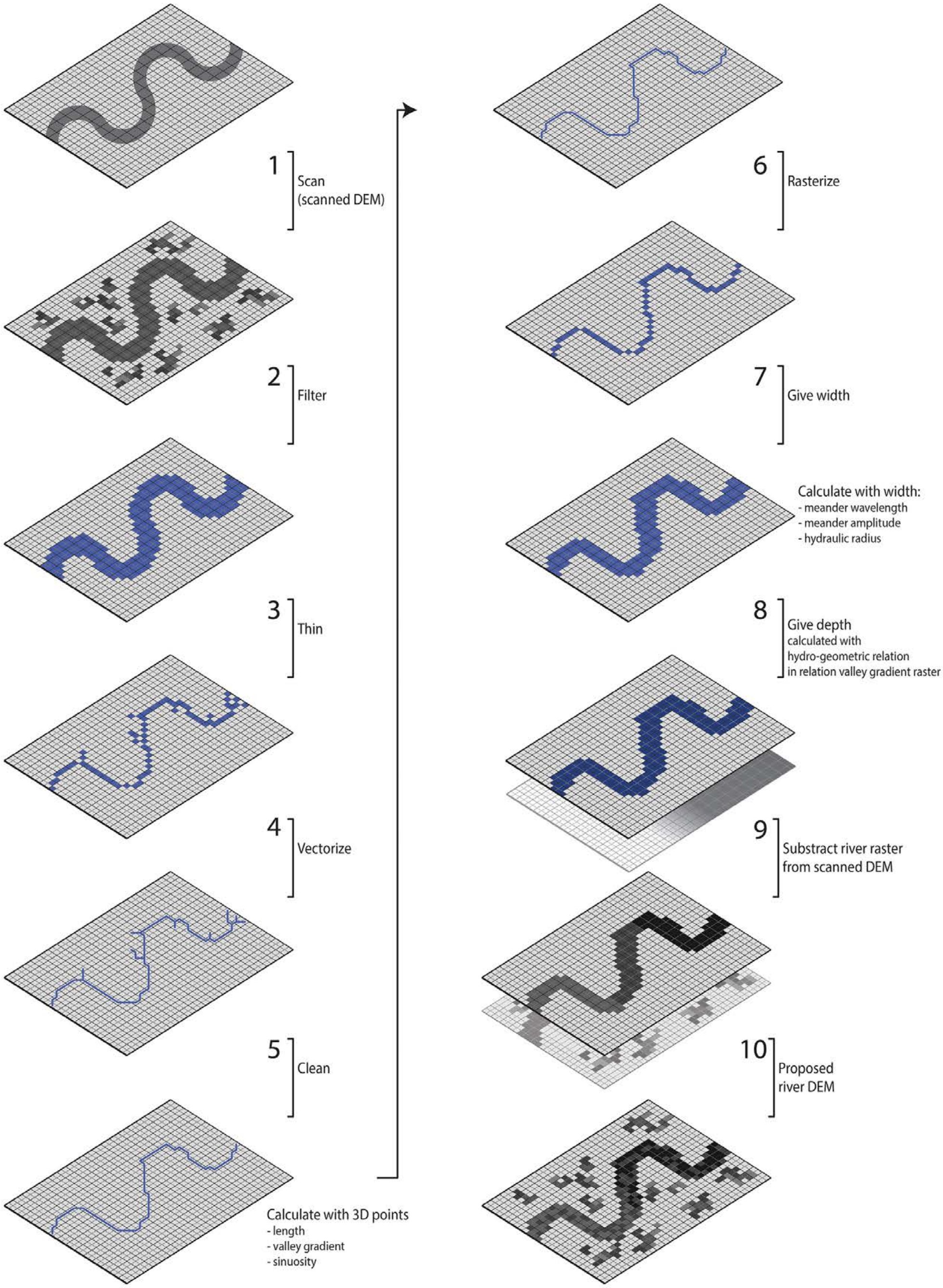

Fig. 3: Schematic overview of the process of designing a waterway using a thread

$$Hydraulic\ radius = S^{-0.2542} * 0.3724 * D_{50} * Q *^{0.6539} * \sigma_s{}^{0.1050} \quad (5)$$

With S denoting the gradient of the waterway, D_x (x = 16, 50 or 84, see below) the grain size in a grain size distribution for which x percent of the weight has a smaller grain size, Q the flow rate and σ_s the composition of the soil defined as $\sigma_s = \sqrt{(D_{50}/D_{16} + D_{84}/D_{50})}$. The hydraulic radius described the ratio between the cross-sectional area (hatched area, Fig. 4), and the wetted perimeter (red outline, Fig. 4).

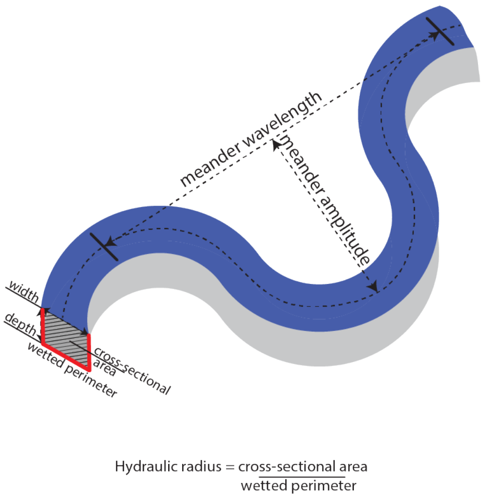

Fig. 4:
Schematic overview of the above mentioned relations: width (Equation 1), depth (Equation 2), wavelength (Equation 3), amplitude (Equation 4), hydraulic radius (Equation 5)

Another describing parameter for design is sinuosity, or tightness of the meander bend, which is expressed as the ratio of the length of the waterway in a given curve to the wavelength of the curve (LEOPOLD & WOLMAN 1960). In other words, the ratio of the length of the centre line of the waterway and the Euclidean distance between the start and end point of the waterway (WILLIAMS 1986).

3 Results

In an educational setting we proposed to use a 3D mould created out of the inverse of elevation data to deposit a mock-up to represent the study area. Waterway design was conducted by using and placing a thread on the mock-up. Regarding the placing of the thread the width, depth, numerical parameters for design, and course of the waterway were calculated and the georeferenced raster cells, as result of the calculation to coincide with the designed waterway changed accordingly. The geometrical changes increased with increasing flow rate. The change of geomorphology, depth and width of the waterway, was indicated by increasingly darker colours. The developed algorithm was carried out for several flow rates (Figure 5A1, B1, C1) and presented results (close-ups in Figure 5A2, B2, and C2 respectively). The developed algorithm proved to work consistently while alternating the placement of the thread. In doing so, different cases with changing geometry; length, direction and degree of bending were tested. In all cases the width of the modelled waterway was larger than the calculated hydraulic-geometric width. At higher flow rates, the difference was found to be larger. The depth of the waterway was observed to follow the calculated gradient of the valley as was intended. In all cases, the resultant length was larger than the calculated length. Both the meander length and meander amplitude increased with increasing flow rate as expected. A final design was realized by taking away sand or adding sand on specified areas. The specific areas were visualized on top of the mock-up as a guide. Positive (blue) values indicated that sand had to be removed while negative (red) values indicated that sand had to be added. White indicated that no sand has to be removed or added.

4 Discussion

Designing with a thread proved to be a straightforward process and may stimulate representative and integrative thinking, and insight into riverine geomorphology, because of the relation between the design (form, scale, size) decisions and hydrological impact. Using a thread-based approach enables the user to design, supported by near real-time iterative results – both visually and numeric – decreasing the needed effort and time, making hydrological processes illustrative and tangible. In our current approach we visualized the new situation as result of the thread-based design, to foster reflection upon design. To support didactics, we believe showing only changes regarding elevation and waterflow between designs offers more input for different adjustments of the final design. To support this, threads of different colours could be used to indicate the used flow rate, eliminating the need to define this manually.

This study assumed that realizing a waterway design by a non-disruptive change of a mock-up will be possible by using additional tools like threads and feedback by visualisation. However, in practice the resolution of the scanner was too low. The resolution of the scanner must be close to the resolution of the raster data to be processed, and to visualize the required changes on the mock-up imposed by the proposed design. Decreasing the extent of the study area would increase the size of the proposed changes, yet decreasing the insight into the larger context. Changes were difficult to interpret due to the small size of design proposals, including the small change in depth compared to the vertical scale, which was already exaggerated 8 times to give greater emphasis. By exaggerating the height, features otherwise not perceptible given the Dutch context and scale of the mock-up could be recognized. However, this could lead to unintended impacts on topological thinking and a possible false perception of the represented landscape.

The thread based approach could be applied as a Research Through Design method, which is applied in engineering-oriented landscape designs where models or simulations are tested and evaluated until an optimised solution is found (VAN DEN BRINK 2016). Our approach enables iterative, and quick simulations accompanied with numeric parameters for evaluation.

Designing with a thread entailed drawbacks as well. Intuitively, the problem with representing the trajectory with a thread is that the physical representation itself is the complete opposite of the phenomena that is represented. While a thread is an elevated structure, a waterway is an excavated structure. Moreover, the thread obscured the visualized results as both covered the same extent. It remains questionable if the calculated depth represents well the intended change as the height of the thread was scanned as well, This caused the surface of the thread to be the initial elevation, instead of the surface level of the mock-up. Fortunately, under-sizing a design leaves room for the waterway to shape itself via morpho-dynamic processes (MAKASKE & MAAS 2015).

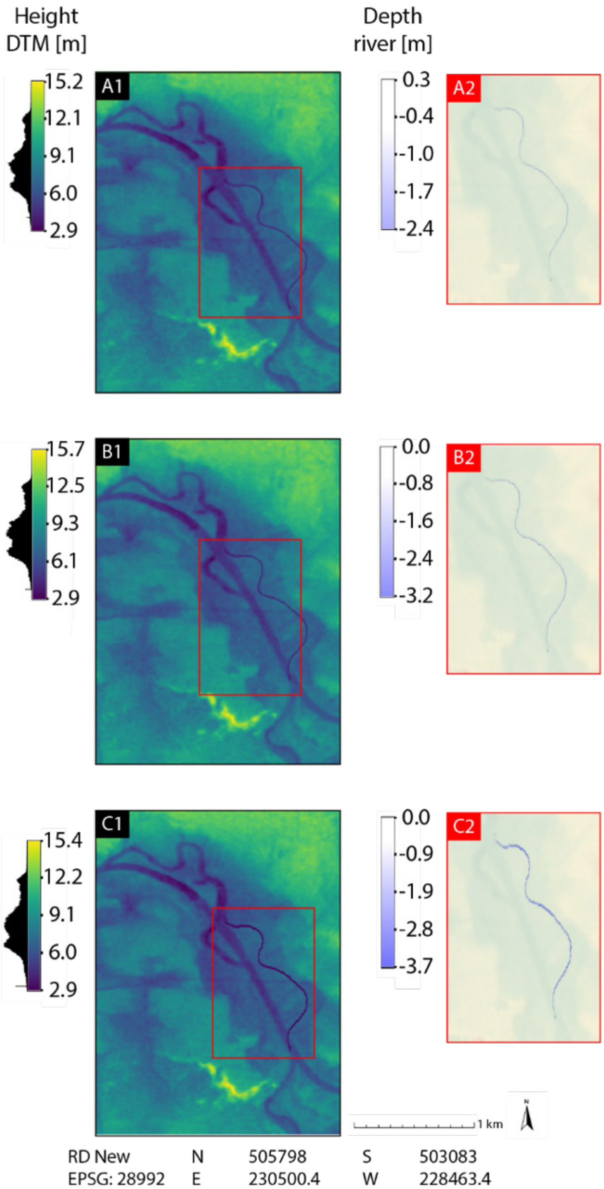

Fig. 5: A1-C1: the waterway design integrated in the scanned DEM is shown. A2-C2: a detailed view of the designs is given as well as the raster values only for the raster cells of the waterway. From top to bottom, the waterway is designed for a flow rate of 3 (A1), 9 (B1) and 15 (C1) cubic meter per second respectively.

5 Conclusion and Outlook

This study presented a specified TL making use of a valid near-realistic mock-up that represented a real world riverine landscape. The developed thread-based design approach enables iterative waterway design and a mean to realize designs by altering the mock-up. TL and the developed thread-based design approach fosters representative thinking, and ultimately makes the impact of the designed waterways on the hydrologic regime by near real-time calculation more illustrative and tangible.

In 2015 a waterway was realized in the study area that was designed with the same principles as applied in this study. The measurements and data of this realized waterway, and of the monitoring afterwards could be used as "ground truth" to further calibrate and validate the functioning of the developed algorithm.

The developed TL will become an instrument in landscape design education after testing the application with professional designers in the setting of projects regarding the redesign of waterways. In the context of education monitoring student experiences and reflections by using this TL is essential to become aware of the added didactical value. Especially the (un)intended impact on topological thinking regarding the change of geomorphology visualised by the projection of the (re-calculated) elevation on the slightly exaggerated height of the mock-up could be nicely studied by using this TL.

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