Digital Terrain Modelling in Landscape Architecture
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1 Introduction

Terrain modelling, being a central discipline in landscape architecture, shapes the ground on which all the structures and functions fit; aesthetic, functional and ecological considerations are simultaneously synthesized into a designed landform. Working the terrain form is a challenging task and requires both simplification and abstraction to make it feasible.

Terrain representation
From a concise historic point of view, over the years grading plans been represented in several styles. Early plans consisted of profile illustrations of the relief. Later, the Renaissance brought the perspective drawings of the landform. More recently in 19th century, plan representations took place, initially with hachures, a way of shading used to emphasize topography. By the end of 19th century, terrain contours were introduced and have been widely used ever since, usually supplemented by spot elevations at key points. Other media such as hypsometric tinting and shaded reliefs have also been used as a way of representing the terrain.

With the exception of 3D scale models, terrain forms of the past were represented in a flat, 2D media. Design concepts and visualizations were presented in plan, section or perspective drawings. The principal role of 2D representation is to make the real world abstract and manageable (Ervin 2001). Computer developments have introduced digital models which allow users to represent the terrain in its three-dimensional complexity and then generate either 2D or 3D visual representations for analysis and presentation (Ervin and Hasbrouck 2001).

These representations are techniques for communicating terrain forms and are used in accordance to the period and the purpose. Landscape designers often adjust the representation technique either for presenting a proposal to a reader, or even to assist their own perception and reading capabilities, this being a way to support the “mind’s eye” in creative thinking and design.

Thinking and designing the landform
It is generally accepted by landscape architects, architects and engineers that contours are the best method for representing three-dimensional landforms in two dimensions on a map or drawing (Petschek 2008). Together with elevation spots, slope arrows, and profiles, they stand for the techniques that most landscape architects use to understand and design the terrain form. A good contour plan must permit the trained mind a quick visualization of landform.

The advent of computers brought changes into the design process. Initially used as drawing machines, they quickly started being used as design machines allowing users to develop
their ideas directly in a digital media. While providing users with drawings that are cleaner, easier to organize and share, they also offer effortless ways of controlling visualization. Designs have been enriched with digital libraries with ever-growing data; and new tools have been developed to assist and simplify the graphic expression of one’s design intentions. But one of the key conceptual leaps introduced by digital models is the fact that they are 3D, allowing a three-dimensional reality to be expressed directly in 3D without the need for a 2D abstraction either by plan, section, profile or perspective view.

Within terrain modelling, a lot has been written and discussed about the use of computers as presentation and analysis tools, but unlike other areas of design such as architecture or design in a broader context, very few people address the question of their use as a design tool. We know that at the present time software allows a fast creation of digital terrain models, as well as its analysis and use for calculations, but there are also new design tools that allow terrain to be designed through objects, and new rich experiences in visualization that together have a potential of changing the design process (Jørgensen 2004).

To address this research, several case studies were developed together with landscape architecture students and professionals. They developed digital terrain models as a response to the design challenges presented, their impressions were recorded and the results evaluated. It was found that digital terrain models can be used throughout the whole design process. Three-dimensional visualization tools endowed users with enhanced understanding of the landform; analysis tools allowed real-time consequence analysis for designed landforms and the establishment of a more dynamic design process. Terrain design tools allowed users to change the landform in an interactive way and granted them an extended language to express their design intentions.

2 Digital Terrain Design - Fundamentals

The language of terrain models - TIN

As already mentioned, due to the complexity of the real terrain, an abstracted and simplified media needs to be used in order to make the landform workable. The most commonly accepted digital media is the Triangulated Irregular Network or TIN. Due to software development, the creation of a TIN data structure is currently a fully automated process; the TIN is no more than the geometric and mathematical consequence of the data it was created on. Most of the time the TIN operates as a hidden computer language which organises all actions into one language (Jørgensen and Lameiras 2007). This allows users to create and interact with a model from a kind of data that they can better understand, contours, points, 2D or 3D lines, among other more intelligent objects such as feature lines, corridors, walls, grading.

Even though the TIN language usually comes as a result of other design media, it is important that landscape architects have a fairly good knowledge of it. Often landscape architects will have to edit the triangulated language through its lines or points in order to correct and adjust their designs. While interacting with a terrain model, the designer frequently has the need to change the way it is visually represented on the computer screen, at times he may need to read contour patterns to see thematic colorations, along with other
visual representations. This not only supports his design development, in addition, it helps reveal problems with the terrain that need to be corrected because they don’t match the designers’ intentions.

**Analysis and consequence analysis tools**
This refers to any kind of analysis tools or visualization media that allow the designer to have a better understanding of the terrain, the design, and its aesthetic and functional consequences. They can be used at any time in the development of a project, for site analysis, validating a design intention or just for visualization or communication purposes.

**Visualization media:**
Digital models are three-dimensional, thus more closely resemble “real-life”. They allow a terrain surface to be seen from different view angles and at different scales by zooming in and out. Model readers choose where to place themselves either at plan, bird’s-eye perspective or at eye-level. Users can have a rich experience of the visualization, any change made into the design is visualized instantly in 3D, and from it users can assess scale, proportion, harmony, and balance of the designed elements in relation to the existing ones. This stimulates the senses into a more exploratory design method, where real-time adjustments in the designs can be made in order to meet personal preferences.

Landscape architects should be aware of how visualization parameters such as light, view angle, materials, atmosphere, etc., affect the perception of the landform in order not to be deceived by them, but in spite of this, use them to their best advantage to enhance perception and bind the parameters to a better understanding of the terrain.

**Analysis tools:**
A terrain model consists of surface information which can be visualized through a series of visual styles which normally include: contours, triangles, points, colour by elevation, colour by slope grading, colour by direction, slope arrows, gridded view and watershed. In addition, profiles, water drops and catchment areas can also be produced to give extra information to the reader. Visual styles can be used in separately or combined, in accordance to the landscape architect’s need at a given moment.

Terrain data can be displayed in a graphical way, through thematic colorations of the terrain model, in accordance to the user selection of ranges. These are defined according to themes of information. For example, colour by slope will use different ranges either if it is for accessibilities analysis, landscape use or drainage analysis. Earthwork calculations allow users to know about volumes, as a consequence of their design, by presenting the amount of soil to be added, removed or moved within the project area. Whenever needed, inquiry tools can be used to ask the software questions about specific terrain regions, lines or points. This includes slope, elevation, 2D and 3D areas. Stormwater management tools such as water drops and watersheds tools can be valuable to identify problems and solutions regarding water runoff. Additionally, more advanced tools for calculating and simulating rain water collected by watersheds are also available within software solutions. They are, however, more suitable within the field of Hydraulic Engineering.
Tools for analysis are the same as those for consequence analysis since they are the ones that provide the landscape architect with comprehensive knowledge about the landform and its functions.

Fig. 1: One model, several representations

**Designing with intentions - Terrain Design Tools**

On a typical terrain design, the landscape architect based on his design intentions starts by visualizing in his brain a terrain shape, which will then be translated into a terrain language, typically contour lines and elevation spots. With the advent of a digital terrain model this is still possible, but new design tools simplify the transcription of the idea into the landform, users will now design a form through objects, and the software will translate it into a surface model which can be seen through points and contours. These objects typically include feature lines, grading, and corridors. Among others, they allow a constant and dynamic revision of the landform, through the user input of new parameters. Besides the direct change of geometry, it is possible to decide how the new objects will relate to the existing landform by inputting values for slope, distance, elevation, desired earthwork volume, or even as within corridors by detailing a desired profile.

Fig. 2: Left: contour lines, the traditional terrain design tool; Middle: objects used for expressing the same terrain shape; Right: The resulting digital model
The design process - Visual Thinking
As Stephen Ervin says, “3D visualizations have taken the place both of final artist’s conceptions, and of designers’ initial sketches and preliminary models. Their role in transforming both the ‘practice’ and ‘poetics’ of landscape architecture is undeniable” (Mach and Petschek 2007). Within digital terrain modelling, creation happens directly in a 3D workspace and design is made with objects. The first drafts of rough digital terrain shapes set the possibilities of a dialogue with the software through consequence analysis. 3D analysis tools are then used to validate or reject a design idea. If any aesthetic of functional problem is detected, users have to revise their designs, and then make new consequence analyses. Each drawing is an answer to a question, which in turn poses the following question (Steenbergen 2008). If the design is validated in the dialogue with the software, users move on to the next stage, detailing their design. Sets of terrain design tools are available and allow users to add detailed to terrain shapes. At any phase of project development, a constant dialogue with the model is present, users have real-time feedback from their design changes.

Fig. 3: 3D Terrain design work method

3 Case studies
At the moment, not many landscape architecture studios are using digital terrain modelling software, and the ones that are rarely do so at more than the representation and calculation level. Since our goal was to experience the use of the software as a design tool, we considered that a way to get a validated experience would be through teaching landscape architecture students at the master level, and landscape professionals, the use of the terrain modelling software, and then, together with them, develop a few case studies entirely in a digital media, while recording their impressions.

Two courses within information technologies at the master level in two different countries, Portugal and Denmark, were used as a basis for the study. Both of them had an average duration of 9 weeks (37 hours per week: theory lessons – 7h, supervised work – 12h and self-study - 18h). Focus was mainly within terrain modelling but participants also had to
express their skills in other areas of landscape design. Furthermore, a similar, but shorter course, lasting 5 weeks (1 day per week – 8h), was organized in Denmark for landscape professionals. In Portugal, a group of landscape architecture professionals was also taught to use the software and then developed real case studies. All the processes were supervised and we could take notes on contributions and challenges introduced by the use of digital terrain models within the development of a design.

The software chosen was Autodesk Civil 3D 2009, due to the fact that the almost everyone were already in touch with Autodesk software and therefore would require less effort to gain knowledge on the user interface. This is also considered by us to be state of the art software within digital terrain models. Besides, from the information we gathered, many offices already have licences of Autodesk Civil 3D but either use it as a standard AutoCAD or don’t really take advantage of the full potential of the software.

All courses were structured in three main stages: The first where landscape architects were taught the software. Each learned about the terrain language TIN, its restrictions and opportunities; terrain analysis, design and calculation tools, software interactions. Afterwards, they were presented a project area and had to develop their own designs, this time assisted and supervised. Here was the time for learning more advanced design tools. The last stage consisted of a more complex terrain project that had to be started from scratch and fully developed until the construction details.

Each person had to experiment with the full array of tools and become skilled at how and when to use them. The goal was to break the initial inertia that comes with using a new software and terrain language, so that in time to the participants were fluent enough to freely express their design intentions into the terrain model (or at least we hoped). This allowed us to learn from their experiences, conclude about the best methods for learning the software, see which tools are relevant for the profession, which need improvement; and more important learn how to get knowledge about the terrain using the software as a support for design decisions. Additionally it made us realise the importance of a correct and structured 3D work method for developing a digital terrain design.

4 Results

Both landscape architecture students and professionals had previous knowledge on how to shape the landform in an analogue way, and express it through the construction of models or by designing with contours and points. This made it possible for them to have a critical approach towards digital models

A three-dimensional model

The use of digital models endowed the participants with a rich experience of visualization, a 3D language in which newer generation users tend to be very fluent due to higher literacy through computer use and games. Overall, participants found that when compared to the traditional representation of terrain either in plan or physical models, the fact that they could change the view point in order to better apprehend a three-dimensional form, and
leave the traditional bird-eye viewpoint to experience the landscape at the user’s point of view (1.7m) gave a better feeling of scale, proportion and composition.

Many students commented on the need to exaggerate the vertical elevation of the model in order to better understand terrain changes. This could be related to the fact that sometimes we have to exaggerate an object’s form in order to better understand it. Landscape architects have always done this almost caricaturized way of representation in their drawings and sketches. It is important though to always be aware that it’s not a true representation of the scale; it’s just an auxiliary tool.

**Visual Styles**
The style used to represent the terrain model has an important role in the perception of the 3D structure by the reader; it was found that most of the times representing a model with a triangulated of grid surface by itself was not enough. Most users still had to either turn on the contour lines (also in 3D) or use a colour by elevation scheme as a way to assist their reading of the landform.

**Interacting with the model**
As mentioned before, a terrain model can be visualized by different styles (ex: contours, triangles, points, thematic colorations) this means that in order to modify the terrain surface we need to interact with the model and not with its visualization. This was tricky for students to understand at the beginning because even though they were visualizing the contours they couldn’t just move them and change the terrain, they had to first modify the model, and then the contours would be visually redesigned to accommodate the new designed form. Users had to learn how to interact directly with the TIN model, and make changes to it. They learned how to add, remove, and edit points and lines, and how to swap edges. This proved to be a crucial task, in particular whenever a new object was added into the terrain, as the intersection areas could be quickly edited.

Getting information from the model – analysis and consequence analysis
Thematic styles such as colour by slope, slope arrows, directions, and watersheds, allowed the participants to ask specific questions of the model. “Which areas are inaccessible for handicapped persons? Which areas are more favourable in terms of sun exposure? Which areas have problems with water runoff? (...)” The landscape architect needs to know which questions to ask, in order to make use of the data in a designed proposal.

Profiles were referred to as a very significant tool both for analysis and design. The fact that they are dynamic and react to any changes in the model allowed the participants to see in real time the consequences of their design. From it, they could see if their changes would “create a problem in water runoff”, “make it too steep”, “create a visual problem”, etc. Participants would divide their computer screen in two and while interacting with the terrain model in one half, they could see the changes in the profiles in the other. As with the terrain model, students often exaggerated the z-factor in the profile.

Watersheds, water drops and catchment areas were pointed to as very efficient tools for preventing problems with water runoff. Among others functions, they were used to test the drainage of a paved area, see if any water was flowing towards the buildings, and identify areas with water retention problems.
The design: tools and forms
Users were pleased with the fact that they could still interact with the model through the “analogue tools” of contours and points and lines. But when taught the new design tools with objects such as grading, walls and feature lines, they realized that they no longer need to compose the intended shape into contours and points, rather they could construct a 3D form and choose how to relate it to the terrain. Contours and points are a consequence of their designed form and are used solely as a visual representation of the form. After a period of adaptation to the software and the language of the models, participants almost always abandoned the use of contours and points at the design phase (with the exception of some special shapes) and replaced them with other design tools, especially the feature line, which is no more than a three-dimensional line which can be used to sculpt any terrain shape and be used as a basis for grading criteria in relation to the existing terrain. Participants highlighted the fact that they could edit the feature lines with elevation, slope or grading criteria and see in real time the model change, and the contour patterns with it.

These tools approach the designed form of landscape architects way of thinking, since there is no need to break down a form into contours and points. In addition participants could interact with these objects and revise them according to their intentions. Not all are fully dynamic which means that at times the objects have to be redefined or even redrawn and be related again to the terrain.

Contours and points were still used, sometime as a design tool, but more often as a way to fine detail the model. Contours were added to soften edgy-looking contours, a consequence of the triangle language. Points were added, removed and edited, this added detail to the model, fixed surface problems and was used to break even or flat surfaces.

Software and the language of terrain
Autodesk Civil 3D software is designed primarily for civil engineers and participants found that with it is quite hard to achieve organic landforms and s-shaped naturalized profile slopes; this is also a common problem with designing in analogue world. Software has great tools to design and control regular slopes; we hope that in future developments we’ll start to see more tools to design organic looking slopes.

Participants agreed on the potentials of digital terrain modelling and the changes brought to the creative process, however the software has a steep learning curve, as not all the tools can be used intuitively. Many students commented on the time spent with software bugs and crashes. Interacting with terrain surfaces and changing the terrain through objects was challenging at the start, but soon after users started becoming more fluent, in a way that they felt almost no restrictions to the forms they could sculpt in the terrain. As (Zelanski 1996) says, “You are working intuitively when you feel a sense of immediacy and oneness with the media”. Understanding the language of the TIN is critical as it opens the door to a better comprehension of the landform and consequently assists the visual thinking process.
Fig. 4: Student group work. Up row: Jacob Damkjær, Linda Johannsdottir, Reka Nemeth, Solveig Sigurdardottir. Down row: Morten Aagaard, Simon Enemærke, Michelle Lauritzen, Bo Nielsen

5 Conclusions & Outlook

The courses acted as an introduction to the potential of digital terrain modelling as a creative and design tool. Together with the participants, we tested out the tools and developed new methods for assisting the creative design. When compared to the analogue way of designing, it was clear that the processes involved made users more willing to try and experience through design, as the tools and methods are more intuitive, dynamic and rich in information.

It was found that through experiencing their designs in a three-dimensional media, enriched with information about the terrain, users could have a better comprehension of the terrain forms and functions. Terrain digital design tools are more intuitive and therefore easier to use to translate the landscape architects design intentions into a shape. This opened up a dialogue between the model and the designer where for each designed shape, the model would change itself and present the new modifications in a 3D language. The reader would then make visual analyses and if needed he would ask the model for more information. The designer could then use a simplified language of objects in order to make changes to the design, and then start a new loop in the design process.

The fact that landscape architects now have a tool which enriches their experience of visualization which, together with intuitive design tools, allows an exploratory design method, supports the conclusion that digital terrain modelling tools adds to visual thinking. This is also supported by two widespread assumptions: the first is that design is not a linear process, but instead comes in loops where the designer often has to revise his/her design decisions. The second is that design is by itself a research tool, as (Steenbergen 2008) says, “A drawing is always the result of a process in which the content and presentation are constantly being sharpened up and developed”.

All participants agreed that terrain modelling depends primarily on the landscape architect having design intentions; they are the source of the designs. Furthermore, it is crucial to
develop a correct work method that will optimize the relation between landscape architects’ thinking and the terrain model.

Further work needs to be done; the focus should be on the 3D work method for terrain. As painters and sculptors have to learn how to control the media they are using to express their designs, landscape architects should learn how to interact with the surface model and how to express themselves through digital terrain tools. Researchers should point out methods and assist the development of new tools that will allow a richer experience of design.

In response to the new terrain design technologies, and using the feedback and information we got both from our courses and landscape architecture professionals, we’ve decided to create a web source of knowledge within digital terrain modelling in landscape architecture. In it, users can learn about design methods and tools through articles and tutorials, and interact with other users by posting questions. This can accessed through the Link www.land-3d.com

7 References


Zelanski, P 1996, Design principles and problems, Fort Worth, TX, Harcourt Brace College Pub.