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Mapping Spaces: Three-Dimensional Visualisation and Design in Landscape Architecture

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Landscape architecture is a complex, multi-faceted field whose practitioners design the spaces in which we live. Landscape modelers now utilise CAD, GIS, and a range of related software to create digital models and produce visualisations of landscapes. Three-dimensional scanning as a visualisation tool involving techniques such as photogrammetry, LiDAR (light detection and ranging), drone-based photography, and other advanced imaging technologies have greatly extended the possibilities for representation and design. In the picture theory of language in the *Tractatus Logico-Philosophicus*, Ludwig Wittgenstein presented a logic of depiction that described a mapping relation captured by the law of projection. In this paper, I explore mapping space, using case studies in modern landscape architecture to demonstrate how Wittgenstein's law of projection illuminates the principles involved in visualisation in contemporary landscape architecture.

Landscape Architecture. 3D visualisation. Wittgenstein.

1. INTRODUCTION

Landscape architects design the spaces that shape how we live. Their projects range in scope from college campuses and neighbourhood plans, to public parks and historic, archaeological, or natural site restorations. They encompass an impressive diversity of environmental needs and social functions, such as healing gardens, sustainable designs, community open spaces, green roofs, and bioremediation. In their introduction to the profession on their website, the American Society of Landscape Architects (ASLA) states that:

> Restoring endangered wetlands, reducing hospital stays, securing government and other buildings, removing toxins from rainwater — these aren't pie in the sky. It's what landscape architects are designing right now...Landscape architects analyze, plan, design, manage, and nurture the built and natural environments (ASLA 2017).

How do they actually meet the challenges involved in accomplishing such complex and multi-faceted goals? In "Landscape Architecture 101: Learn What Landscape Architects Do", the ASLA remarks the "tiny voice inside a landscape architect's head often whispers, 'Can you actually build this thing?'" (ASLA 2017). How do they design and build the projects that shape the spaces in which we live?

Design in landscape architecture is a collaborative process involving big ideas, multiple visualisations, and engagement with all the professionals and stakeholders to address the pertinent issues and technical difficulties encountered in conceiving and constructing the project. "In addition to solving the design challenge, landscape architects collaborate with architects, engineers, and construction teams to make sure the design can and does get built" (ASLA 2017). This does not include other stakeholders, such as the client, or the public whose lives will be affected by the project. How do you help them visualise the project faithfully?

To design and build a project, landscape architects construct models: models of the terrain and its accompanying features, and models representing the designed space. These models allow all interested parties to visualise spaces: the terrain with which the landscape architect is presented and the conceptualised space of the design.

The visual thinking central to this kind of modelling is an important feature of many creative disciplines, from engineering, to the sciences, to architecture. Ludwig Wittgenstein's picture theory of language in the *Tractatus Logico-Philosophicus* develops a logic of depiction based on a law of projection. It illuminates the principles involved in visual thinking across a variety of disciplines and informs the design techniques involved in the digital modelling of the landscape architect. I will argue that Wittgenstein's philosophy can provide valuable insights into the methods of landscape modelling and the practice of landscape architects, a rapidly developing and expanding field with implications beyond its own discipline.

2. WITTGENSTEIN'S *BILD* THEORY: THE LOGIC OF DEPICTION

The visual thinking informing modeling has played a critical role in engineering and architectural design. It was central to the work of landscape gardeners and the new discipline of landscape architecture that grew out of that tradition in the nineteenth century. It is at the heart of Wittgenstein's philosophy in the *Tractatus,* as one of the most influential philosophers of the twentieth century began his career as a design engineer.

Wittgenstein's career as a dominant force in philosophy at Cambridge University is how most scholars remember his life. There is far more to this story, however. He received his engineering certification at one of the most prestigious technical institutes on the continent, the *Technische Hochschule* at Charlottenberg-Berlin, at a time when hands-on experimentation and mathematical drawing were at the heart of its curriculum. In “Wittgenstein and the Mind's Eye,” I argued that:

> The engineer’s ability to visualize an invention, to solve design problems by creatively altering configurations of its elements, calls for a kind of constructive, spatial, synthetic thinking that is also crucial for a certain type of scientific imagination. Before he studied philosophy under Bertrand Russell at Cambridge, Ludwig Wittgenstein’s education was technical and scientific. His formal training and postgraduate research prior to approaching Russell to study logic were directed toward shaping the mind of a sophisticated research engineer. The visual thinking involved in the mathematical drawings of engineering design trains the mind’s eye to picture how the elements of a structure function in combination with one another. This kind of visual thinking plays a critical role in the *Bild* theory of language in the *Tractatus Logic-Philosophicus* (Hamilton 2001, p. 54).

In his account of the role of mathematical drawing in engineering design, Peter Booker’s “main theme” involves descriptive geometry and “the representation of three-dimensional objects on a two-dimensional surface” (Booker 1963, p. xv). In Wittgenstein's engineering training, the ability to envision such representations was central to visual thinking in design. To shape this engineering mindset and teach engineers to think in terms of three-dimensional objects represented on a two-dimensional surface, mathematical drawing – in particular, descriptive geometry – has historically been used to train the mind's eye for design.

Working through the issues involved in the *Notebooks*, Wittgenstein would ask himself “What is the ground of our – certainly well founded – confidence that we shall be able to express any sense we like in our two-dimensional script?” (Wittgenstein 1961a, p. 6e). He answers this question in his famous picture theory of language.

The key word in the picture theory of language, '*Bild*,' has customarily been translated as picture. But, as David Stern explained,

> Wittgenstein used the German word ‘*Bild’* to talk about the model, a term usually translated as ‘picture’; as a result, the theory of meaning it inspired is generally known as the picture theory. While both words cover such things as images, film frames, drawings, and paintings, the idea of a three- dimensional model is more readily conveyed by the German ‘Bild’ than the English ‘picture'…it is important not to be misled: the theory involves generalizing from what models, pictures, and the like...have in common, and treats two-dimensional pictures as just one kind of *'Bild’* (Hamilton 2001, p. 91).

In the *Bild* theory, Wittgenstein presented a logic of depiction in which the visual thinking central to his theory is explained in the law of projection. He saw his *Bilder*, or models, in a projective relation to reality. For him “a *Bild* is a model of reality” (4.01).

Before examining Wittgenstein's engineering mindset, we must consider his description of the ontology of the *Tractatus* in its first propositions. He asserts that ‘the world is all that is the case’ (1), and ‘the world is the totality of facts, not of things’ (1.1). The definition of states of affairs specifies that ‘What is the case – a fact – is the existence of states of affairs’ (2), and ‘a state of affairs (a state of things) is a combination of objects (things)’ (2.01). It is not objects standing alone, unrelated to each other, that constitute the world, but objects as they exist in combination, related to one another in states of affairs. Existing states of affairs make up what is the case.

How is it possible for things to combine in states of affairs? ‘The possibility of its occurring in states of affairs is the form of an object’ (2.0124).

> 2.0271 Objects are what is unalterable and subsistent; their configuration is what is changing and unstable.
>
> 2.0272 The configuration of objects produces states of affairs.
>
> 2.03 In a state of affairs objects fit into one another like the links of a chain.
>
> 2.031 In a state of affairs objects stand in a determinate relation to one another.
>
> 2.032 The determinate way in which objects are connected in a state of affairs is the structure of the state of affairs.
>
> 2.033 Form is the possibility of structure.
>
> 2.034 The structure of a fact consists of structures of states of affairs.

The form produced by the configuration of objects can be the structure of a state of affairs. To ascertain what actual structure exists in the world, one must check to see which of the possible combinations of objects actually occurred. How is this related to his engineering worldview?

Wittgenstein spent seven years of his life before he came to Cambridge first training to be an engineer, then pursuing research in aeronautical engineering. How did his engineering background shape his philosophical mindset? Eugene Ferguson writes,

> Many features and qualities of the objects that a technologist thinks about cannot be reduced to unambiguous verbal descriptions...they are dealt with in the mind by a visual, nonverbal process. The mind's eye is a well-developed organ that not only reviews the contents of a visual memory but also forms such new or modified images as the mind's thoughts require. As one thinks about a machine, reasoning through successive steps in a dynamic process, one can turn it over in one's mind. The engineering designer, who brings elements together in new combinations, is able to assemble and manipulate in his or her mind devices that as yet do not exist (Hamilton 2001, p. 55).

Engineers visualise inventions. They solve design problems by creatively altering configurations of their machine elements. Engineering drawings represent these thoughts, communicating the engineer's ideas from their tentative beginnings in thinking sketches to the precision of the technical blueprints. Wittgenstein brought this mindset to the *Tractatus*.

In Wittgenstein's engineering training, using models of working parts of machines to teach machine construction was standard. Polhem's 'mechanical alphabet' represented the mechanical movements necessary for the design of complex machines. "The five 'powers' of Hero of Alexandria: the lever, the wedge, the screw, the pulley and the winch, were the vowels of his mechanical alphabet. No 'machine limb (could) be put into motion without being dependent on one of these" (Hamilton 2001, 70). This alphabet of objects, whose configurations produced working inventions, gave engineers a tacit understanding of the component parts of machines and the principles underlying the forms of machines, allowing them to visualise these elements combined in new configurations. Wittgenstein's coursework used models of machine elements intensively, and a widely used set of kinematic models was created by Professor Franz Reuleaux of the *Technische Hochschule*.

To understand the *Bild* theory, visualise individual machine parts in your mind's eye. Imagine how they can actually be combined to form a functional machine. The forms of the parts determine how they can stand in relation to one another in a machine that will work. There are many possible, yet predetermined (as only certain combinations are possible), structures that can exist. The forms of the parts (objects) determine the possibilities of different structures of machines (possible states of affairs). The actual combination of parts (configuration of objects) realised depends on which of those possibilities was realised in the construction of the machine. "If I know an object, I also know all its possible occurrences in states of affairs. (Every one of these possibilities must be part of the nature of the object)" (2.0123).

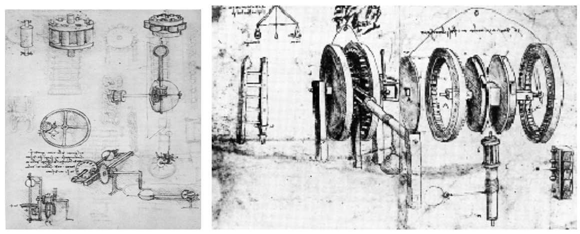

Figure 1a & 1b: *DaVinci's Machine Elements*

Engineers visualise the structure of a projected machine; they think through how the principles will work in the mind's eye. Spatial thinking, the ability to see the form or configuration of a structure in space, is crucial for understanding the possibilities of the invention. Analysing Morse's invention of the telegraph, Brooke Hindle developed this thought:

> His great strength remained a quality of mind that permitted him to manipulate mental images of three-dimensional telegraph components as well as complete telegraphic systems, altering them at will and projecting various possibilities for change and development (Hamilton 2001, p. 65).

Morse himself wrote that 'painting and her sister arts of design rely upon form displayed in space'

(Hamilton 2001, p. 66). 'Form displayed in space' is an excellent characterisation of the structure of states of affairs in the *Tractatus*.

Visualising machine elements in their different possible configurations would have been second nature to Wittgenstein. Understanding the *Bild* theory from this perspective is unusually concrete, but "that utterly simple thing, which we have to formulate here, is not a likeness of the truth, but the truth.(Our problems are not abstract, but perhaps the most concrete that there are)" (5.5563).

The Tractatus is a difficult, and sometimes highly abstract work. Yet, Wittgenstein's insight into the *Bild* theory involved reflecting on the use of a scale model of an accident in a Parisian law court.

> It was in the autumn of 1914 on the Eastern Front. Wittgenstein was reading in a magazine about a lawsuit in Paris concerning an automobile accident. At the trial, a miniature model of the accident was presented before the court. The model here served as a proposition, that is as a description of a possible state of affairs. It had this function owing to a correspondence between the parts of the model (the miniature houses, cars, people) and things (houses, cars, people) in reality. It now occurred to Wittgenstein that one might reverse the analogy and say that a proposition serves as a model or picture, by virtue of a similar correspondence between its parts and the world (Von Wright 1984, p. 18).

In a proposition, we combine names (representing objects) to represent 3D states of affairs.

> 4.031 In a proposition a situation is, as it were, constructed by way of experiment. Instead of, "this proposition has such and such a sense," we can simply say, "This proposition represents such and such a situation."

To construct propositions experimentally, we test them against reality. They answer yes or no, true or false, in order to represent reality. That is their truth-value. A *Bild* that is realised as a structure of a state of affairs has represented something true about reality.

In 4.0311 he repeats the idea of spatial objects standing in relation to each other. "One name stands for one thing, another for another thing, and they are combined with one another. In this way, the whole group – like a tableau vivant – presents a state of affairs." Names in propositions present states of affairs in a tableau vivant? Names as signs for objects, objects as concrete as real tables, chairs, and books, standing in relation to one another, for, after all, "logic is interested only in reality. And thus in sentences only in so far as they are pictures of reality" (1961a, p. 9e).

So, how is the law of projection related to design in landscape architecture? Descriptive geometry is described as "the geometry in which figures are represented and their properties investigated and demonstrated by means of projection" (Willson 1909, p. 2), Furthermore, "properties of figures that remain unaltered by projection are called projective," allowing faithful representation from 2D to 3D models, and back again. "With a digital model, you can represent terrain in its three-dimensional complexity and then generate either 2D or 3D representations for analysis or presentation" (Ervin & Hasbrouck 2001). As we will see, the law of projection captures what makes such a landscape model work.

3. LANDSCAPE MODELING: "YOUR ENVIRONMENT. DESIGNED." (ASLA 2017)

The discipline of landscape architecture took shape in the nineteenth century, developing out of the traditions of landscape gardening. Both drawings and models played central roles in those traditions. Digital landscape modelling, though, is less than forty years old. Its techniques were developed by researchers, academics, and programmers in fields such as the military and the entertainment industry. Thus, my argument extends beyond landscape architecture, connecting with my earlier work presented in EVA conferences on motion capture.

In *Landscape Modeling: Digital Techniques for Landscape Visualization*, Stephen M. Irving and Hope H. Hasbrouck intended to create a work that would bring together techniques from these disparate fields. They were "most concerned with model making as part of a design conception and communication process, with a heavy emphasis on the visual" (Ervin & Hasbrouck 2001, 4). It won the Merit Award from the ASLA, presenting "the state of the art in using CAD, GIS and related software to create digital models and produce visualisations of landscapes and landscape elements--notably landform, vegetation, water and atmosphere" (ASLA 2017). The authors note that:

> Digital tools and techniques are widespread, and used not only by landscape architects...allied professionals and various kinds of digital artists are engaged in making models of landscapes, from advertising backgrounds to video games and Hollywood sets. (ASLA 2017).

They are both well versed in traditional pen and pencil representational techniques. They note the continuity from traditional training to the digital era, with "very similar goals: to produce images (usually, but more generally, models and representations) in the process of design inquiry and communication" (Ervin & Hasbrouck 2001, p.

xi). In this case study, we are most interested in how the basic principles involved in modelling and visual thinking inform design and digital modelling in landscape architecture, and how Wittgenstein's logic of depiction can illuminate those principles.

From the perspective of a landscape architect:

> Landscape modeling depends upon basic computer graphics, 3D modeling, and GIS software techniques and conventions, but...requires attention to the specific challenges of modeling landscape elements: landform, vegetation, water and atmosphere (Ervin & Hasbrouck 2001, p. 36).

Those “four essential elements of the landscape, – landform, plants, water and the atmosphere” are described as the traditional “palette” of the landscape architect – “the essential components of the natural world” (Ervin & Hasbrouck 2001, p, 1).

> The terrain is basic to the framing of the model. Landform, or terrain, is the basis of any landscape, forming the roughly horizontal foundation upon which all else is arrayed...In landscape visualizations distant landform provides the context within and against which other landscape elements are perceived, and the mid- and foreground structural base upon which other elements sit (Ervin & Hasbrouck 2001, p. 39).

The three most important forms of digital representation of terrain are 2D drawings, 3D surface models, and 3D solid models. We will focus on digital representation of the terrain for the purposes of this argument.

How do you create a model that represents a three-dimensional terrain? Reviewing the geometries used for modeling could be helpful at this point.

> The most common models we know of in the design world are 2D: drawings, photographs, maps, plans, sections, projections, et al....positions in 2D space, whether on paper, the surface of the earth, or a computer display screen, can be described by a pair of numbers, representing distance along two orthogonal axes whose crossing is labelled the origin...typically called *x* for the horizontal, or width dimensions, and *y* for the vertical, or height dimensions. On a spherical surface like the earth, they are called longitude and latitude...These units are most often found in surveying and cartography...GIS software is usually equipped...to convert between projections (Ervin & Hasbrouck 2001, pp. 13–14).

Functionality as well as faithful representation is affected by failure in accuracy between projections.

The simplest landform surface will be a flat plane, but terrains are not always simple or uniform.

> The real world in which we operate, the alternative worlds designed by landscape architects and urban planners, and even the imaginary worlds imagined by computer game designers...is usually thought of as being three-dimensional (3D)—occupying the spatial dimensions, *X* (width), *Y* (breadth), and *Z* (height, or depth) (Ervin & Hasbrouck 2001, p. 8).

This is the basis for Computer Aided Designed (CAD) and Geographic Information Systems (GIS). “2D models are represented in a plane, 3D models have volume and a third axis *Z* orthogonal to the vertical and horizontal axes of the 2D plane. So a point will have three coordinates *x,y,z.*”

> Whereas 2D models are described in 2D *planar* space, 3D models occupy a volume of space....Among three-dimensional objects, there is an important distinction in computer modeling: between pure *surfaces*, which may exist in three dimensional space, and are more than a single flat plane, but are mathematically infinitely thin, having only a front side and a back, and *solids*, which have thickness and an interior and exterior (Ervin & Hasbrouck 2001,p. 18).

Many modelling systems create surfaces by default. They are easier to represent than solids. Solids are more complex, with more attributes to represent.

In 2D landscape drawings, terrain is represented by contour lines and spot elevations. Spot elevations represent measurements of the landscape. Contour lines based on the measured spot elevations represent horizontal slices of the terrain corresponding to the height of the contours of the terrain or the imagined elevation of the plan. For

> landscape architects...making 2D schematic drawings (plans), a stylized conventional form of representing landscapes by spot elevations and contour lines is used. These are often the base data from which a digital model is created. Surveyors capture spot elevations and use mathematical formulae to interpolate the elevation, height and location of contour lines. These curved, closed, non-intersecting lines trace the imaginary beach lines that would be formed by water at various elevations (Ervin & Hasbrouck 2001, p. 43).

Digitally represented contour lines in 2D models are connected series of spot elevations, and this data can also be used to create tables of data linked to the model. “Land surveyors produce data on landform by recording spot elevations at irregular intervals...Each spot elevation data point consists of three values: *x*, *y*, and *z* coordinates. So spot elevations can be represented as a table with columns *x, y*, and *z*” (Ervin & Hasbrouck 2001, p. 43). The database can be used for further analytical purposes, and more data can be incorporated and used to shape the model. A common "source of data and potential database linkage is *Geographical Information Systems* (*GIS*) software" (Ervin & Hasbrouck 2001, p. 29).

These representations are used to create the 3D models informed by this data, and those 3D models are used in turn to create further "2D data structures for analog representation on paper. With a digital model, you can represent terrain in its three-dimensional complexity and then generate either 2D or 3D representations for analysis or presentation" (Ervin & Hasbrouck 2001, 49). The quality of the models and the data they provide, as well as their usefulness as visualisations, depends on the faithful projection between models. To be useful for model building, contour lines in CAD drawing must have their elevation explicitly set – every line must have explicit z-coordinates.

While 2D and 3D models are made up of the graphical and geometric features described here, they can also be linked to other databases that flesh out the models. A geometric file of a forest may include each tree's location as a 3D spot location, matched to a terrain model's elevation, but information about species, and size, and other characteristics may be stored in a separate data file (Ervin & Hasbrouck 2001). When linked, this database can provide important realistic detail for the model's representation of the landscape.

> Conversely, other programs might be able to read the information from a 3D model file, and extract information for useful calculations. For example, two terrain models, one describing existing, and the other showing proposed conditions, can be used to determine the total difference in volume, or cut-and-fill requirements, between the two models (Ervin & Hasbrouck 2001, p. 10).

A variety of 3D data structures can be used to create three-dimensional digital terrain models. A

> common data structure for a digital elevation model is...a raster grid: a rectangular array of numbers, each representing the elevation (z) value of the land at each point x,y located on a rectangular grid....the simplest visualization of a raster grid data set is a fish net grid, made by drawing lines from the center of each grid cell to its four rectangular neighbors (Ervin & Hasbrouck 2001, p. 51).

When used as a wireframe representation, it is a straightforward, effective tool. The most important variable decision to make for these models is the size of the grid cell – too small and the file size is enormous and cumbersome, too large and the representation of the surface may be too coarse.

Although the regular rectangular gridded meshes of the fishnet projections work well in many ways, they have drawbacks. For a more detailed projection of the terrain features being modelled, a Triangulated Irregular Network (TIN) can be used. Irregularly spaced and located spot elevations are joined together in a continuous network of triangles. A common method is Delaunay triangulation, connecting each point only to its nearest neighbours, and capturing more features of the terrain than the uniform rectangular net, creating a more representative model.

When pictured in the mind's eye, the projective, wireframe representations central to landscape modeling bear a striking resemblance to the wire frame presentation of the rig used in computer animation and motion capture. The rig is critical in the creation of CG characters. Visually, it looks like a 3D mesh sculpture of the character on the computer screen, and:

> the movements of CG characters are created using that representation. It is through the rig that the animated character acts, performing its role in the story...The one important tool you need to create good animation is your rig. The rig is the puppet you use to animate with on the computer…Your rig is your character…With a clean and simple model design and a solid rig, you are on your way to creating a memorable character…the relationship between animator, modeller, and rigger in CG is the most important factor in creating a solid design (Hamilton 2013, p. 4).

Other instances of projective representation in landscape modelling, such as rendering, ray tracing, etc., could be mentioned, and if space permitted much more could be said. The projective relations that drive landscape modelling should be clear, however.

Picturing how the points on a figure in space are represented in a 2D mathematical drawing, and how point to point correspondence makes modelling in landscape architecture effective, consider the following propositions:

> That is how a picture is attached to reality; it reaches right out to it. It is laid against reality like a measure. Only the end-points of the graduating lines actually touch the object that is to be measured. So a picture, conceived in this way, also includes the pictorial relationship, which makes it into a picture. The pictorial relationship consists of the correlations of the picture's elements with things. These correlations are, as it were, the feelers of the picture's elements, with which the picture touches reality (2.1511–2.1515).

These feelers mirror how landscape modelers convert from 2D schematic drawings, to 3D models and render back to 2D models. They are like the projective rays of the descriptive geometer.

4. THE SKY IS NO LONGER THE LIMIT: PHOTOGRAMMETRY AND REMOTE SENSING IN THE TWENTY-FIRST CENTURY

Photogrammetry, or measurement based on photographic images, began with the birth of photography in the nineteenth century, but has experienced explosive growth since the end of the twentieth century. The development of computers after the WWII changed the field.

> it was the rapid advance of electronic computing that made the analytical treatment by photogrammetric methods a reality. Mathematical modeling...improved the speed, accuracy, and economy of photogrammetric production and enabled the exploitation of imagery from a wide range of sensor designs. The basis of such modeling is to express analytically the geometric relationships among points in the object space, the perspective center in the lens, and images on the photographs, based on the mathematical discipline of projective geometry (McGlone & Lee 2013, p. 21).

The International Society for Photogrammetry and Remote Sensing (ISPRS) defines the field as:

> the art, science, and technology of obtaining reliable information from noncontact imaging and other sensor systems about the Earth and its environment, and other physical objects and processes through recording, measuring, analyzing and representation (isprs.org).

The National Oceanic and Atmospheric Administration (NOAA) defines remote sensing as “the science of obtaining information about objects or areas from a distance, typically from aircraft or satellites” (oceanservice.noaa.gov) An important source of remote sensing data is LiDAR (Light Detection and Ranging). NASA describes LiDAR as:

> A lidar uses a laser (light amplification by stimulated emission of radiation) to transmit a light pulse and a receiver with sensitive detectors to measure the backscattered or reflected light. Distance to the object is determined by recording the time between the transmitted and backscattered pulses and using the speed of light to calculate the distance traveled (earthobservatory.nasa.gov).

Enormous numbers of points are measured on a surface with these scanning technologies. The measurements become large sets of data points in a coordinate system, point clouds.

> These techniques generate huge amounts of high-resolution data...LiDAR acquires highly accurate elevation data at a resolution of one point per square meter or better and routinely generates hundreds of millions of points. It is not possible to store these massive data sets in the internal memory of even high-end machines, and the data must therefore reside on larger but considerably slower disks (Argawal et al. 2017, p. 2).

In three-dimensional co-ordinate systems, points in a point cloud are represented by *x,y,z* coordinates and can be used to represent the external surface of an object. The output of 3D scanning technology, point clouds can be converted to 3D surfaces. When managing 3D scanning data, a common request is for conversion of point clouds into more practical triangular meshes. This can be accomplished by a variety of methods, such as polygon mesh models (representation of a shape where a curved surface is modelled as small faceted flat surfaces).

These technologies are used to study archaeological sites, with Airborne Laser Scanning (ALS) being described as:

> one of the most important innovations in data collection...in archaeology....laser scanning makes multiple measurements and combines them into a precise collection of coordinates. These coordinates are normally stored as a point cloud, from which information on the morphology of the object being scanned may be derived. Photogrammetric approaches also produce 3D point clouds describing the shape of an object based on the triangulation of matched points from multiple images (Opitz & Cowley 2013, p. 1).

Photogrammetry and remote sensing technologies are now used in many disciplines and have become much more accessible. UAV photogrammetry and LiDAR have become available to anyone with access to drones, cameras, and apps, with websites providing information on buying and using affordable equipment.

For landscape modelling, 3D scanning is cheap, accessible, and user friendly in many (but not all) ways. Design firms are using it with mixed results.

> Architects and engineers use it to help create as-built drawings of bridges and buildings and for “clash detection” when designing additions or renovations of historic structures. Urban planners use it as a visualization tool when modeling different development scenarios. Anything that can be 3-D scanned can be 3-D printed, and numerous municipalities now have scale models of their cities in physical form (Barth 2017).

For landscape architects, it could be a tool for design, “a way to generate a perfectly scaled 3-D model of any site”. In practice, it's not easy. The size of the files is one problem.

> The data sets that result from 3-D scanning are enormous, and can crash a computer in a heartbeat. It’s not unusual for LiDAR data to take days, even weeks, for software to process (Barth 2017).

Surveyors, however, have embraced 3D scanning, which presents opportunities for landscape architects. “The technology is a means to create the ultimate basemap.” Tate Jones, a surveyor specialising in 3D scanning believes it is:

> faster, more precise, and able to capture almost limitless detail about a site. The resulting “point cloud” of data, he says, is best imagined as a 3-D mesh consisting of millions of geo-referenced points—if not billions or trillions, depending on the scope of the project—over which a 360-degree photo of every inch of the site can be draped...It’s like having a 3-D hologram of the environment on your computer (Barth 2017).

At the site-specific scale, which is important to landscape architects, point cloud data can be uploaded to landscape architecture software, but

> It's hard to filter out the background noise with the organic forms of the landscape. when you have an uneven ground plane, trees, plant material—it all gets muddled (Barth 2017).

While it may take years to realize, there is great promise.

> What was once the exclusive purview of the military and the world’s biggest technology companies is now in the hands of the average design firm—a powerful tool with as yet unimagined applications for the common good (Barth 2017)

5. CONCLUSION

We can now consider the most complete presentation of the logic of depiction and the law of projection presented in the Tractatus.

> 4.01 A proposition is a picture of reality. A proposition is a model of reality as we imagine it.

> 4.011 At first sight a proposition—one set out on the printed page, for example—does not seem to be a picture of the reality with which it is concerned. But neither do written notes seem at first to be a picture of a piece of music, nor our phonetic notation (the alphabet) to be a picture of our speech. And yet these sign languages prove to be pictures, even in the ordinary sense of what they represent...

> 4.014 A gramophone record, the musical idea, the written notes, and the sound waves, all stand to one another in the same internal relation of depicting that holds between language and the world. They are all constructed according to a common logical pattern.

> 4.0141 There is a general rule by means of which the musician can obtain the symphony from the score, and which makes it possible to derive the symphony from the groove on the gramophone record, and, using the first rule, to derive the score again. That is what constitutes the inner similarity between these things which seem to be constructed in such entirely different ways. And that rule is the law of projection which projects the symphony into the language of musical notation. It is the rule for translating this language into the language of gramophone records.

The law of projection allows us to translate faithfully from the musical score, to the gramophone record, and derive the score again, because what is projected is their logical form. The internal relation of depicting based on the law of projection is a perfect analogy for landscape modelling, where the projective relations between 2D and 3D models and the data that shapes them creates beautiful structures and informs creative design.

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