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Methods for understanding spatial-visual characteristics in landscape design

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Mapping landscape spaces: Methods for understanding spatial-visual characteristics in landscape design

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ABSTRACT

Mapping landscape spaces by means of manual and modern technology enables landscape architects to describe, understand, and interpret spatial-visual properties of landscape. This can help to strengthen the body of knowledge of spatial design in landscape architecture through measurement and visualization of common concepts in the field, as well as through the possibility to explore spatial-visual landscape features that was not possible before. Despite the wide ranging possibilities and the methods available for mapping landscape spaces, there is evidence that its potential is often still underutilized mainly due to a lack of awareness. This paper aims to contribute to the increase of awareness by providing an overview of mapping methods and tools that can be used to study spatial-visual characteristics in the field of landscape architecture, and show the potentialities of its application by brief examples. This paper introduces six categories of mapping methods: compartment analysis, 3D landscapes, grid cell analysis, visibility analysis, landscape metrics, and eye-tracking analysis. These methods are used to explore, for spatial design in landscape architecture, crucial spatial-visual categories sequence, orientation, continuity, and complexity in an analogue and digital way. The Vondelpark, a well-known urban park in the Netherlands, is used to exemplify how the spatial features can be mapped by means of the mapping methods.

1. Introduction

Description, understanding, and visualization of landscape spaces is at the heart of spatial design in landscape architecture. This is because landscape designs are among three-dimensional constructions that articulate the visual manifestation of open spaces, surfaces, screens and volumes and their relationships (Simonds, 1998; Motloch, 2000; Doherty and Waldheim, 2016). The basic premise is that the shape of space, plasticity and appearance of spatial elements in the landscape determine the relationship between design and perception. Landscape design as such addresses the form and functioning of three-dimensional landscape space, which creates an intended or unintended spatial dynamic, such as a spatial sequence, opening up a landscape panorama, or producing optical illusions. The underlying spatial-visual mechanisms of the spatial dynamics are an important subject to study. Not only to understand what spatial effects can be achieved by conceiving certain spatial compositions, and to be able to communicate about it, but also to strengthen the theoretical foundations of the discipline.

There is a long tradition of mapping landscape spaces in the field of landscape architecture. Mapping landscape spaces is about getting a grip on spatial-visual properties of landscape through manual and digital produced visualizations. Manual methods for operationalising landscape characteristics are hand-drawn maps, sketches, and schematic diagrams etc. (e.g. Simonds, 1998; Loidl and Bernard, 2003; Dee, 2005). These methods are powerful tools for understanding and describing spatial qualities, which assists in communicating certain spatial design concepts and intentions (Pinzon Cortes et al., 2009). With the development of digital technology, digital visual representations are becoming more widely used in the field of landscape research and design such as photomontages, computer models, 2D and 3D photo-realistic visualizations, as well as real time interactive presentations, and virtual reality (VR) environments (e.g. Ervin, 2001; Dinkov and Vatseva, 2016; Bianchetti, 2017; Lin et al., 2018; Bruns and Chamberlain, 2019). They are widely used to help mimic existing or proposed landscapes, and assess or predict environmental/landscape change. Digital visualizations of landscape designs are mostly used for presentation and communication of ideas, but the interpretation of these visualizations remain relatively subjective, which is problematic for knowledge acquisition and decision-making (Ervin, 2001; Bishop and Lange, 2005).

On the other hand there are advanced methods, devices, new algorithms, and types of data that enable the development of indictors of certain landscape features. These mostly quantitative approaches have the potential to measure and visualize spatial-visual aspects of landscape space and deepen the knowledge of their relationship to ecological, morphological, and/or geographical features (e.g. Palmer and Roos-Klein Lankhorst, 1998; Antrop, 2007; Weitkamp, 2010; Sunak and Madlener, 2016; Swetnam and Tweed, 2018; Wang et al., 2019). However, these methods are generally used to address planning and policy-oriented landscape issues related to agricultural, ecological and urban sustainability. Despite the widespread availability of digital methods and measurements are hardly used in the field of landscape architecture for analysis, and description of spatial-visual aspects of landscape. The link between the possibilities the technology has to offer in this respect and the practice of landscape design remains underdeveloped. Prejudice and lack of awareness in landscape architecture seems to be the most important reason for this (e.g. Drummond and French, 2008; Göçmen and Ventura, 2010; Nijhuis, 2016).

This paper aims to contribute to the increase of awareness by providing an overview of mapping methods and tools that can be used to study spatial-visual characteristics in the field of landscape architecture, and show the potentialities of its application by brief examples. This paper introduces six categories of mapping methods: compartment analysis, 3D landscapes, grid cell analysis, visibility analysis, landscape metrics, and eye-tracking analysis. These methods are used to explore, for spatial design in landscape architecture, crucial spatial-visual categories sequence, orientation, continuity, and complexity in an analogue and digital way. The Vondelpark, a well-known urban park in the Netherlands, is used to exemplify how the spatial features can be mapped by means of the mapping methods.

2. Methods for Visual Landscape Research in Landscape Architecture

Landscape architecture can be broken down in mainly three principle knowledge areas: landscape planning, landscape design, and landscape management (Stiles, 1994). Here the focus is on landscape design which is concerned with spatial form and meaning, the development of design principles, and the organization of a physical, functional, and aesthetic arrangement of a variety of structural landscape elements to achieve desired social, cultural and ecological outcomes (Nijhuis, 2015). The cultivation of spatial intelligence in landscape architecture is therefore of crucial importance. In visual landscape research, the development of knowledge on spatial-visual aspects of landscape space is put forward as an important knowledge field. Mapping landscape spaces is the main subject of visual landscape research. Visual landscape research integrates landscape architecture concepts, landscape perception approaches, and mapping methods and techniques (Nijhuis et al., 2011). In the field of landscape perception research there is a vast amount of theories, methods and applications available that can be divided in two main discourses: Expert approaches and public preference approaches (Sevenant, 2010). In the expert approaches the analysis and evaluation is performed by experts and trained observers, such as landscape architects, geographers, etc. In public preference approaches psychophysical, psychological, and phenomenological methods are used to test or evaluate visual properties and experience of the landscape. Though both discourses are not mutual exclusive, this article focusses mainly on expert approaches to visual landscape research, the mode in which landscape architects usually operate in.

Literature reveals that there are predominantly six dominant mapping methods available for visual landscape research (updated and adapted from Nijhuis et al., 2011):

- *Compartment analysis:* considers the visible landscape as a set of concave compartments and the maps are used to distinguish the

relationship between space and mass from a vertical perspective.
- *3D landscapes:* identifies the visual landscape from an observer's point of view, which utilizes two- to three-dimensional visualizations and addresses spatial-visual characteristics horizontally.
- *Grid-cell analysis:* evaluates the landscape by calculating different spatial properties by means of grid-shaped polygons or raster cells.
- *Visibility analysis:* is a three-dimensional visibility calculation based on raster analysis, which shows the geographical area visible from a given position from the observer's perspective.
- *Landscape metrics:* conducts a spatial analysis of land-use patches in landscape ecology, in which quantifies potential metrics of landscape compositions and configurations vertically via raster or vector.
- *Eye-tracking analysis:* is a system that records eye movements and fixations while observing scenes in-situ to interpret spatial-visual characteristics.

These spatial-visual landscape mapping methods can be categorized according to horizontal or vertical perspectives, and qualitative-quantitative approaches (Fig. 1). The horizontal perspective explores the landscape from an observer's point of view and addresses the spatial-visual characteristics from an eye-level perspective. The vertical perspective considers the landscape from 'above' and analyses spatial patterns and relationships from the map view (Nijhuis, 2011). Qualitative approaches here are termed as the empirical interpretation of observation, while quantitative approaches gathers numerical information or translates knowledge into numbers in order to describe and analyse certain phenomena more objectively (Kanagy and Kraybill, 1999).

In order to understand and describe the visual manifestation of landscape spaces, how space is organised, and what ordering principles play a role, landscape architecture has also a specific vocabulary that is fundamental to the discipline. Several researchers elaborate on the two- and three-dimensional physical layout of the landscape architectonic composition and provided vocabulary to describe the spatial construction of spaces, paths, edges (i.e. surfaces, screens, objects), foci, thresholds, and visual relationships like sequence, sightlines, and panorama (e.g. Simonds, 1998; Motloch, 2000; Dee, 2005). In landscape research, the emphasis is often on quantitative clues in the form of landscape indicators that link measurements, spatial descriptions, and performances, such as 'proximity', 'connectivity', and 'coherence' (McGarigal and Marks, 1995; Tveit et al., 2006; Salat, 2011).

To get a grip on the vast amount of spatial-visual design vocabulary, this paper uses four dominant categories of design vocabulary, which
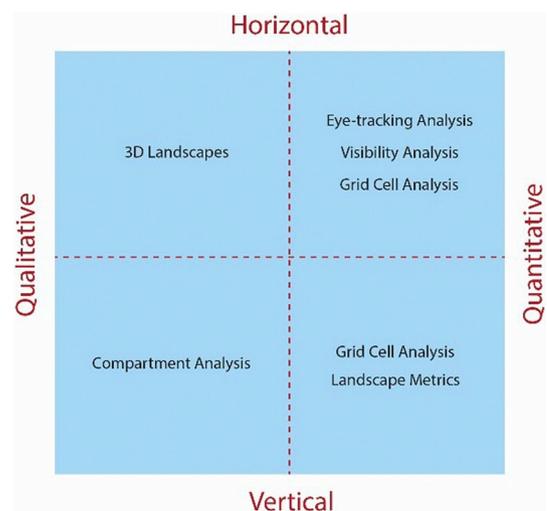

Fig. 1. Characteristics of different mapping methods and tools.

are commonly used in landscape architecture to explore the spatial-visual phenomena related to landscape design: sequence, orientation, continuity, and complexity. The six mapping methods will be used to address the four spatial-visual features or design characteristics commonly used in landscape design.

- Sequence: concerns a series of ordered objects which directs the visual experience along movements (e.g. serial vision, alternate enclosure, vista).
- Orientation: indicates the sense of physical movement and visual access within landscapes to aid way-finding (e.g. a sense of direction, prospect and refuge).
- Continuity: states the relative degree of connectivity of some layouts to each other, which causes adjacent spaces to be a group in a composition (e.g. continuous surfaces or edges, visual and physical accessibility).
- Complexity: suggests richness of spatial and visual elements contained in a landscape scene (e.g. richness/diversity of the view).

3. Case study and data sources

3.1. Case study – Vondelpark, Amsterdam

In order to showcase the potential of mapping methods for visual landscape research, Vondelpark (Amsterdam, Netherlands) is used as an example (Fig. 2). The Vondelpark is an urban park designed in the 19th century which employed spatial principles of English landscape design. This included important hallmarks such as the concealment of boundaries, the illusion of endless water bodies, spatial sequences and continuous views (Pevsner, 1956; Hirschfeld, 2001; Steenbergen and Reh, 2003, 2011). The emphasis was very much on creating an internal oriented spatial experience that had hardly any spatial-visual relationships with the surrounding urban context. As a result, the park is an important learning case for spatial-visual design. Moreover, as an important urban park in the Netherlands, data accessibility and physical accessibility (i.e. fieldwork) helped to evaluate and refine the results of the mapping study.

3.2. Mapping tools and data sources

As mentioned above, six potential mapping methods of spatial-visual landscape are used to explore the primary spatial design characteristics in such a way that the feasibility and peculiarity of different mapping methods can be compared. Considering that each method has its specific characteristics a variety of tools and data is needed (Table 1).

4. Applications of spatial-visual landscape mapping methods

In order to explore possibilities of mapping spatial-visual characteristics, the six mapping methods are applied to evaluate and describe earlier mentioned four categories of design vocabulary, addressing space from qualitative and quantitative perspectives. The tools are used in a rather intuitive way to address the form and function of three-dimensional landscape spaces. They are selected based on their potential to explore particular spatial-visual phenomena common in landscape design such as: framing of views, serial vision along a route, identifying dominant visual landscape elements, etc.

4.1. Compartment analysis

In compartment analysis the visible landscape is considered a set of concave compartments that can be characterized by size, shape, the type of border, and their content (De Veer and Burrough, 1978; Nijhuis et al., 2011). Compartment analysis always utilizes maps to distinguish the relationship between space and mass in qualitative or quantitative terms and understands landscape architectonic compositions from a vertical perspective. Conventional schematic diagrams includes hand drawings, graphic illustrations, topographic maps, and aerial photographs. These are often used to show landscape morphology in the design process (see, for applications, Simonds, 1998; Motloch, 2000; Dee, 2005; McEwan, 2018; Koh, 2019). Spatial network analysis, as a specific form of compartment analysis, represents and quantifies physical configurations as a whole at different scales (e.g. Kofi, 2010; Van Nes, 2011; Telega, 2016; Wernke et al., 2017; Boeing, 2018).

4.1.1. Sequence

Sequential experience follows what people see and perceive when moving along a certain trajectory. Fig. 3a shows a mapping of a sequence revealing the variation of the water bodies' shapes. Linkages among spaces, foci, and thresholds create spatial sequences that have a certain rhythm (as an example see Fig. 3b).

4.1.2. Orientation

The circulation pattern has a direct influence on the orientation of space, the winding patterns of the route convey the spaces themselves

Fig. 2. Left: Digital Terrain Model with heights in metres (Actueel Hoogtebestand Nederland, 2019); Right: Orthogonal Aerial photograph of the Vondelpark (Google Maps, September 2019).

Table 1
Tools, platforms, and data for different mapping methods.

	Compartment analysis	3D landscapes	Grid cell analysis	Visibility analysis	Landscape metrics	Eye-tracking analysis
Tools & platforms	Pen & sketchbook; Depthmap	Pen & sketchbook; Camera; SketchUP	SegNet, and Excel; GIS	GIS & Excel	GIS, Fragstats	Eye-tracking hardware & software
Data	Field survey; CAD map	Field survey; Photograph; photomontage; 3D model	Photograph; Field survey & GIS data (vector)	GIS data (raster)	GIS data (raster)	Photograph or video

a-sequence

= accelerated flow
→ relaxed flow

b-sequence

+ landmarks (main facilities)
• short pause/threshold
↔ connection (visual/accessible connection)

c-orientation

▬▬ cycling path (circuit)
—— walking path (natural shape along water features)
⊞⊞⊞⊞ walking & cycling path (crowed with visitors)
— · — walking path (connecting main facilities)

d-orientation

↔ spatial elasticity (indicates the visual/accessible orientation of the space)

e-continuity

↔ visual open (visible)
⟺ physical open (accessbile)
⟸⟹ visual and physical open

f-complexity

A. organic shaped edges with geometric structures inside
B. organic shaped edges with organic compositions inside
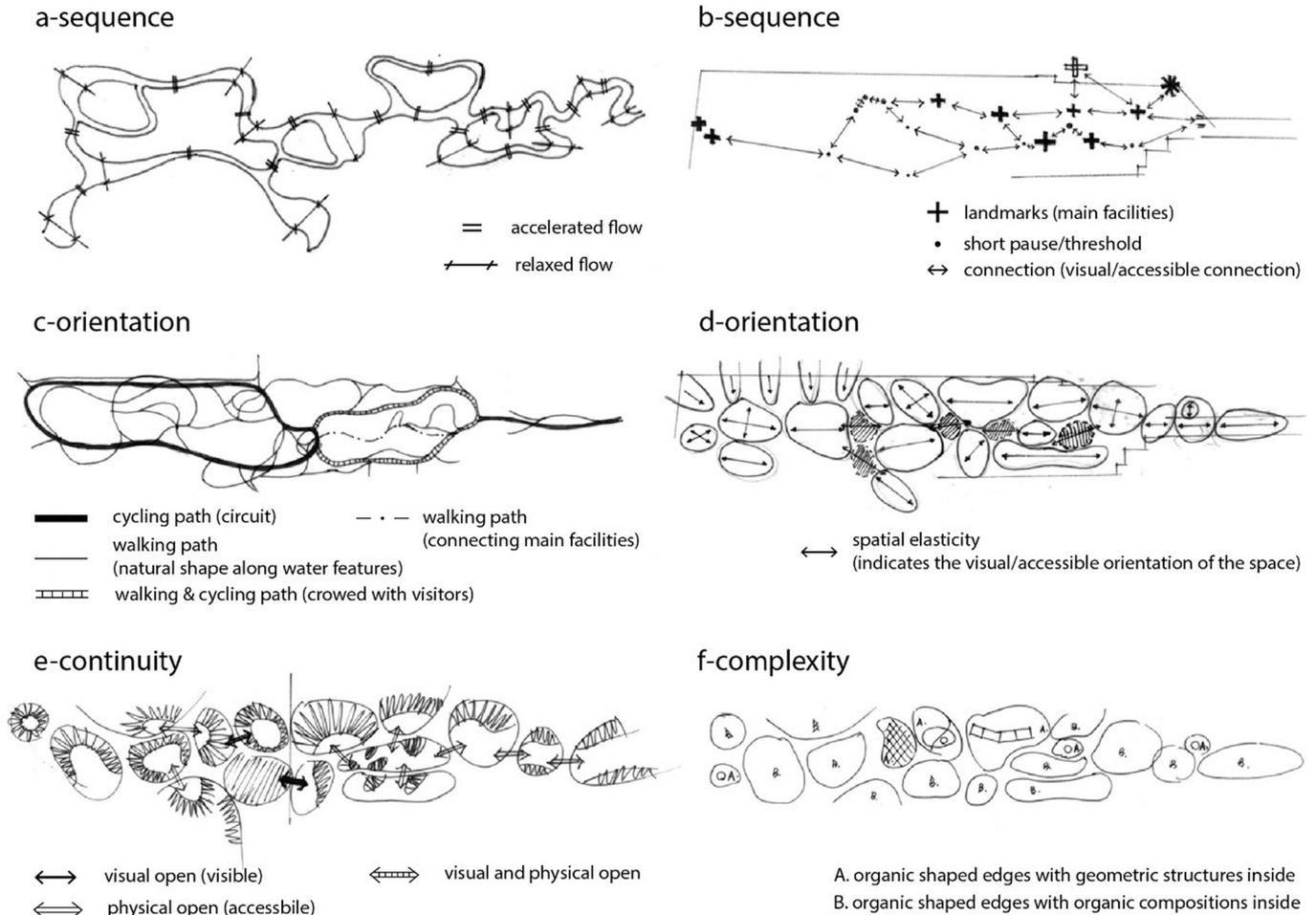
Fig. 3. A series of hand-drawn maps employing compartment analysis to describe the spatial-visual organization of Vondelpark (Field survey, January 2019).

and open different perspectives on them (Fig. 3c). The resulting oval-shaped spaces have an elongated orientation along the long side (Fig. 3d).

4.1.3. Continuity and complexity

Fig. 3e evaluates the degree of openness of the edges of each spatial unit and their relationships in terms of visual and physical continuity. The shape of the spaces addresses aspects of spatial complexity. Fig. 3f shows the form of the spaces ranging from curving edges and geometric internal structures, while others only are characterized by curving shapes.

4.1.4. Integration as measure for orientation

Although hand-drawn diagrams help to map the spatial-visual organization of landscape directly and efficiently, it lacks scientific evidence which can demonstrate findings. In this case, indicators, such as integration and connectivity from space syntax, can provide

complementary and verifiable clues quantitatively. To view landscape space as a whole, integration describes the average depth of a space compared to all other spaces. It calculates how close the origin space is to all other spaces and shows its relative position in the open space system: how better integrated how more people will experience it (Klarqvist, 1993; Montello, 2007). As visible in Fig. 4, the values of the two entrances along the Van Baerlestraat are the highest, which implies that these spaces have the highest degree of accessibility and con-nectedness. Important scenic spots and open views of the park are located here to draw attention and pull people into the park. In addition, the value of the Stadhouderskade entrance (1.432) in the northeast is higher than the Amstelveenseweg entrance (1.323) in the southwest, which indicates the direction of flow of the park is more likely to be from northeast to southwest.

4.1.5. Integraton as measures for continuity and complexity

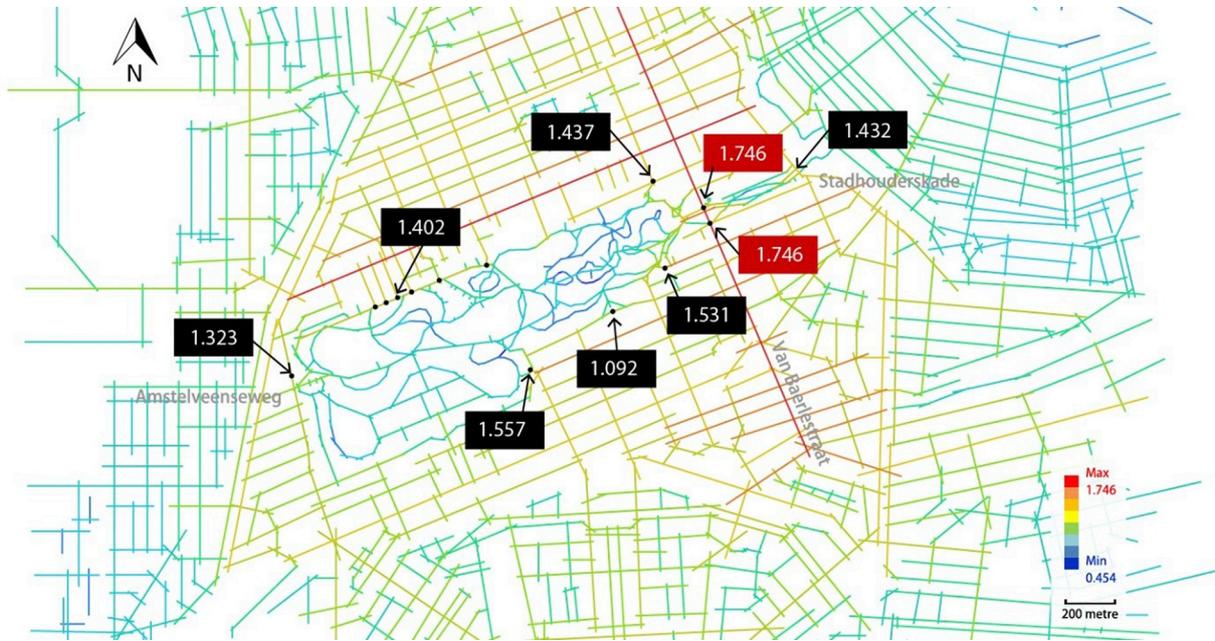The continuity of spaces can also be analysed using an axial map

Fig. 4. Axial analyses provides a means to understand the movement flow through and in the Vondelpark (Axial map based on Open Street Map data, 2019).

which helps to evaluate the position of a certain space in the whole spatial system. The red lines in Fig. 5 indicate paths with a high level of integration. The spaces here are mainly used for service functions connected to key facilities in the park (e.g. monument, pavilion, stage, and cafés). Some segments have a similar integration index (0.730 and 0.732) but represent a different spatial organization. The north section consists of a dense and visually enclosed edges result in an enclosed atmosphere, while the diverse and visual open edges of the south section are open and accessible. This contrasting spatial character in edges strengthens the variation in spatial experience.

In general, compartment analysis provides important clues of the relationship between space and mass. Traditional descriptive maps, for example drawn by hand, are used to present the landscape characteristics in relation to the spatial-visual organizations of the landscape. Quantitative mapping methods like space syntax help to understand inner mechanisms in the landscape compositions and configurations,

which enables spatial designers to address landscape qualities in a more objective way. Compartment analysis mainly focuses on mapping spatial attributes from a vertical perspective, and neglects the visual properties of the landscape from a horizontal perspective.

4.2. 3D Landscapes

3D landscapes identifies landscape spaces from an observer's point of view utilizing three-dimensional visualization, and addresses spatial-visual characteristics from a horizontal perspective. Important means for 3D landscapes are sketches, photographs, photomontages, and virtual landscape techniques, such as landscape modelling, virtual reality, and 3D display based on GIS (e.g. Ervin, 2001; Punia and Pandey, 2006; Bianchetti, 2017; Lin et al., 2018; Bruns and Chamberlain, 2019). This eye-level landscape evaluation tools not only can provide spatial attributes and visual organizations of static landscapes (e.g. Simonds, 1998;
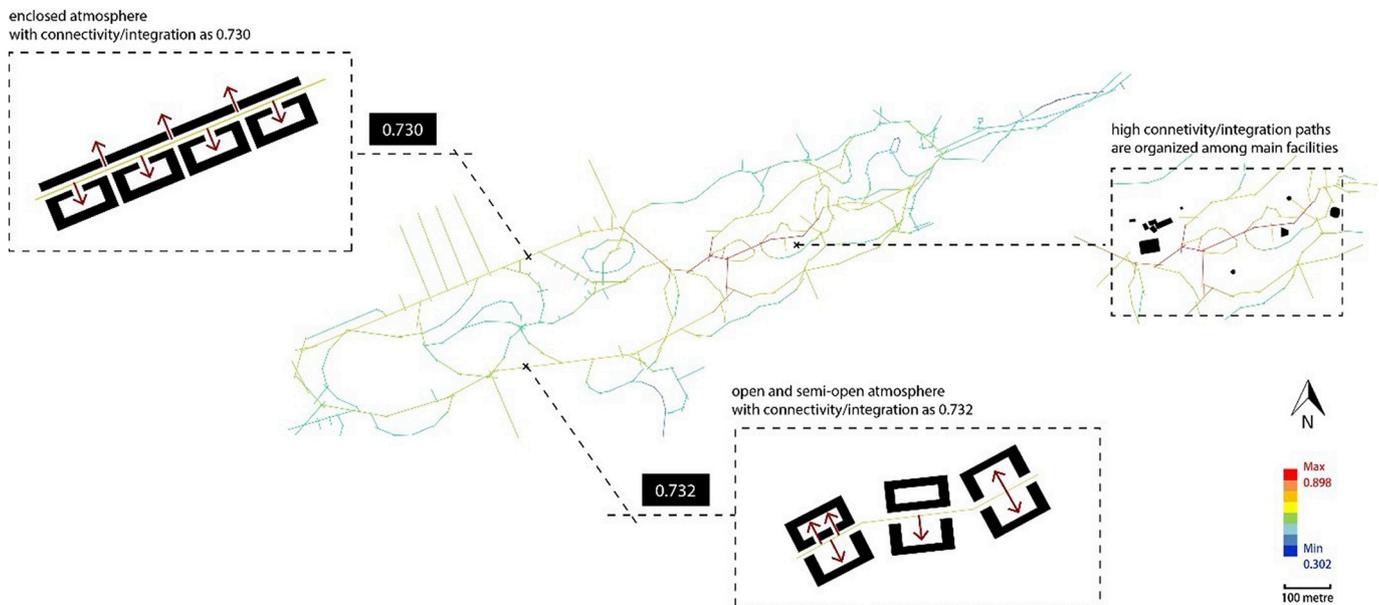

Fig. 5. Analysing the visual and spatial composition along the path (Axial map based on Open Street Map data, 2019).
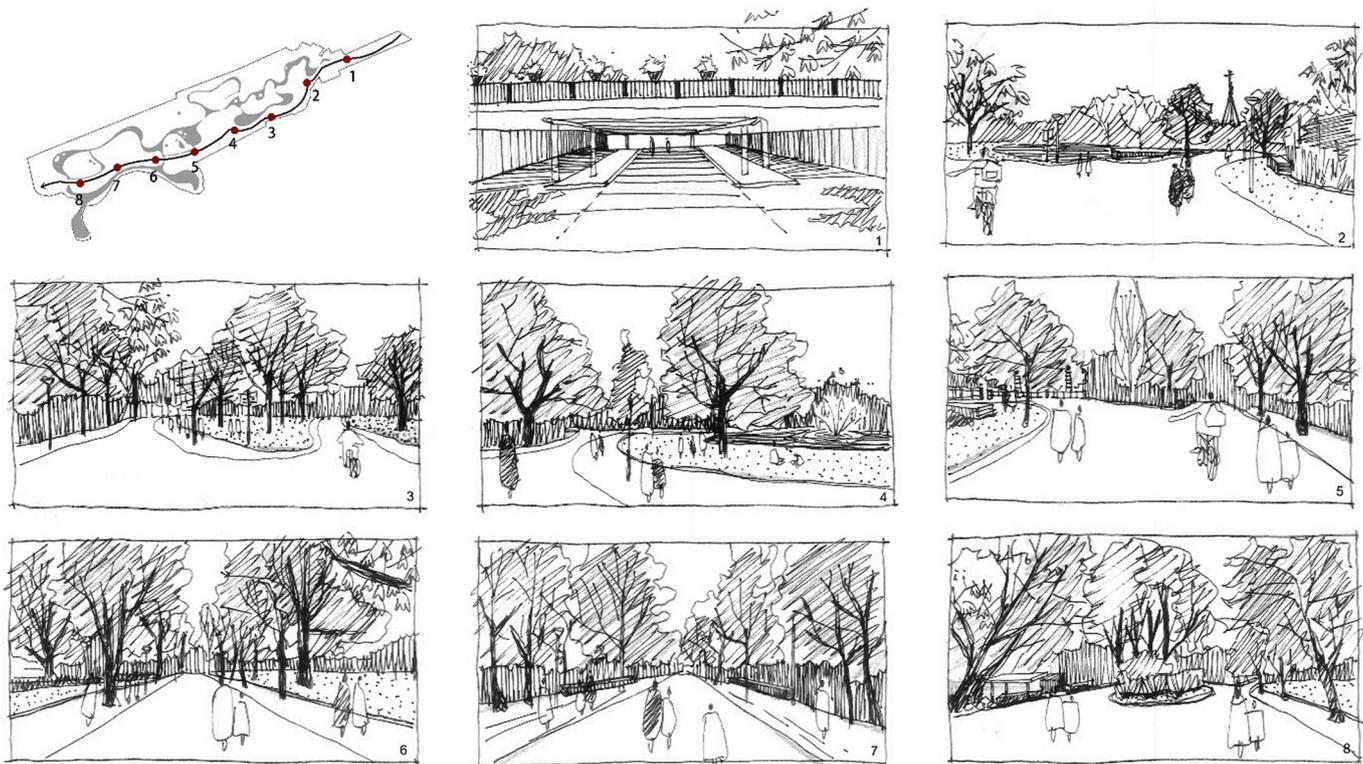
Fig. 6. Mapping serial vision analysing a spatial sequence in the Vondelpark (Hand drawn in the field, May 2019).

Ervin, 2001; Bell, 2012), but can also reveal dynamic properties via serial visions (e.g. Cullen, 1961; Ţălu et al., 2016). 3D landscapes are also often used for visual landscape assessment studies (for elaboration, see Lange, 2001; Tveit et al., 2006; Cureton, 2016; Lindquist et al., 2016; Liu and Schroth, 2019).

4.2.1. Sequence

Cullen (1961) proposes the concept of a serial vision, which shows a series of scenes, jerks, and revelations to present the sequence of space. Fig. 6 shows eight scenes at equal distance along an important route in the Vondelpark. The analysis points out that the landscape architect employed a wide variation of spatial-visual features (e.g. permeability of the edge, landmark, orientation of the path) to create a sequential experience that arouses the eye of the visitor and affords continuous movement.

4.2.2. Orientation, continuity, complexity

Instead of hand-drawn sketches, photographs are also an effective medium to grasp spatial-visual three-dimensional effects. For example, in Fig. 7 two vegetation-shaped thresholds within Vondelpark are indicated. The left one is an open gateway affording continuous physical movement, but a fountain in another direction attracts more visual attention and makes the observer pause for a moment. The right scene shows a visual threshold that combines physical and visual directions.

Architectonic features like bridges, monuments, gateways, or natural elements like a hill or a water feature are an important type of point-reference in landscape spaces that direct the eye of the observer. They are often used to attract the attention in order to guide users through the landscape. For instance, a series of landmarks can visually "pull" the visitor along a route. Once you arrived at a landmark, another one becomes visible and indicates the next destination etc. Fig. 8 shows 3D models of crucial architectonic structures in the park, and are grouped by specific categories, which are threshold/gateway, threshold/transition, and landmark/attraction.

Compared to compartment analysis, 3D landscapes provides

possibilities to address landscape space from a horizontal perspective. Both sketches and advanced visualization technologies have their advantages and difficulties in analysing spatial-visual aspects of landscape space. For example, where sketches can be made quickly often have a subjective connotation; the use of digital technology is time-consuming but is usually regarded to be more objective.

4.3. Grid cell analysis

In grid cell analysis the landscape is analysed by subdividing spatial features into raster cells or grid-shaped polygons. Each feature is described by one of more variables and can be integrated in each cell (Nijhuis et al., 2011). The calculations are often based on selected landscape features derived from digitized historical maps, topographical maps, or orthogonal aerial photographs, or acquired by field surveys. For each grid cell variables like the number of patches, patch density, land type diversity are calculated to show the composition and configuration of landscapes (e.g. Dijkstra and van Lith-Kranendonk, 2000; Van Eetvelde and Antrop, 2009; Stokes and Seto, 2018). In addition, video and photographs can be used to compute landscape characteristics via coding landscape objects in scenes and panorama's (for example see, Palmer and Roos-Klein Lankhorst, 1998; Bishop et al., 2000; Badrinarayanan et al., 2017; Dong et al., 2018).

4.3.1. Sequence

SegNet is a scene understanding tool via pixel-wise semantic segmentation that can be seen as an useful tool to interpret spatial-visual landscape characteristics. It was developed to model the appearance of architectonic structures, and to understand the spatial-relationship within images (Badrinarayanan et al., 2017). Through deep learning, SegNet provides accurate encoding and decoding for multi-class landscape scenes. It identifies different landscape elements by colours, and automatically performs a composition analysis (Fig. 9). Here, SegNet is used to map sequential experiences based on the degree of openness. Landscape photographs are collected from 21 viewpoints along Path 1

Fig. 7. Mapping the connection of the Vondelpark by photographs and illustration (Photos taken May 2019).

with 100 m equidistance. In the analysis of the photographs, landscape components such as a trees, buildings, street lamps are regarded to be visually enclosed, while elements like water, grassland, sky, road, pavement, are regarded visually open. In Fig. 10 measurements on the proportion of open-enclosed views are visualised and show the degree of openness changes along movements. From viewpoint 1–7, open and enclosed scenes along the two paths alternate. After that, scenes on Path 1 are more visual enclosed, and the overall trend is relatively stable. Applying the same mapping method on Path 2, scenes appear to be more enclosed, but with sudden changes. For this type of grid cell analysis via SegNET is important to mention that how the shorter distance between each viewpoint, the more precise the variation of openness can be calculated.

4.3.2. Continuity

Grid cell analysis can also derive multi-dimensional clues from the vertical perspective. Robinson (2016) for instance defines the permeability of an enclosure and states that every scene can be characterized by a visual enclosure and a physical enclosure. Edges of a space above

eye-level with solid structure are perceived as visually enclosed. Open or low edges are visually open. Edges that stop movement via structures (e.g. big shrubs, ground cover) at/above knees height are regarded physically enclosed, otherwise physically open. Fig. 11 shows a visually and physically open viewpoints along the path system in Vondelpark, and calculates point density based on grid cell analysis through ArcGIS. Merging the two layers, a map is drawn showing the permeability of an enclosure, which indicates the continuity of space along the route system in the park. It shows that compared with the east, the western part of the park has hardly any visual and physical connection with the surrounding neighbourhoods, which might reflect the intention of the designer to conceal the boundaries of the park.

As shown grid cell analysis can be helpful to analyse spatial-visual characteristics from both vertical and horizontal perspectives, while combining qualitative and quantitative approaches. Different forms of data and sources, such as photography and fieldwork, can be employed for measurements that enable more objective knowledge acquisition and communication.
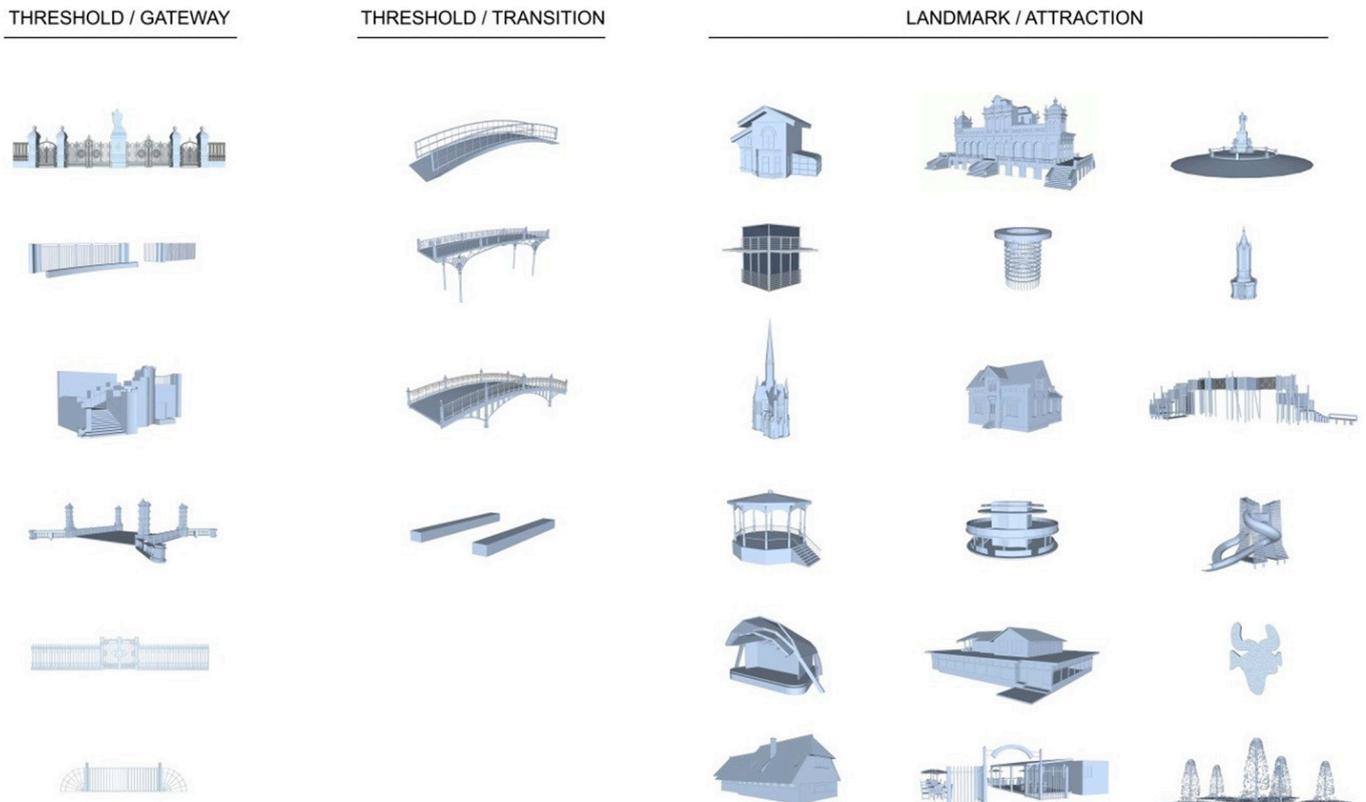

Fig. 8. 3D models of architectonic elements in Vondelpark with different types of functions.
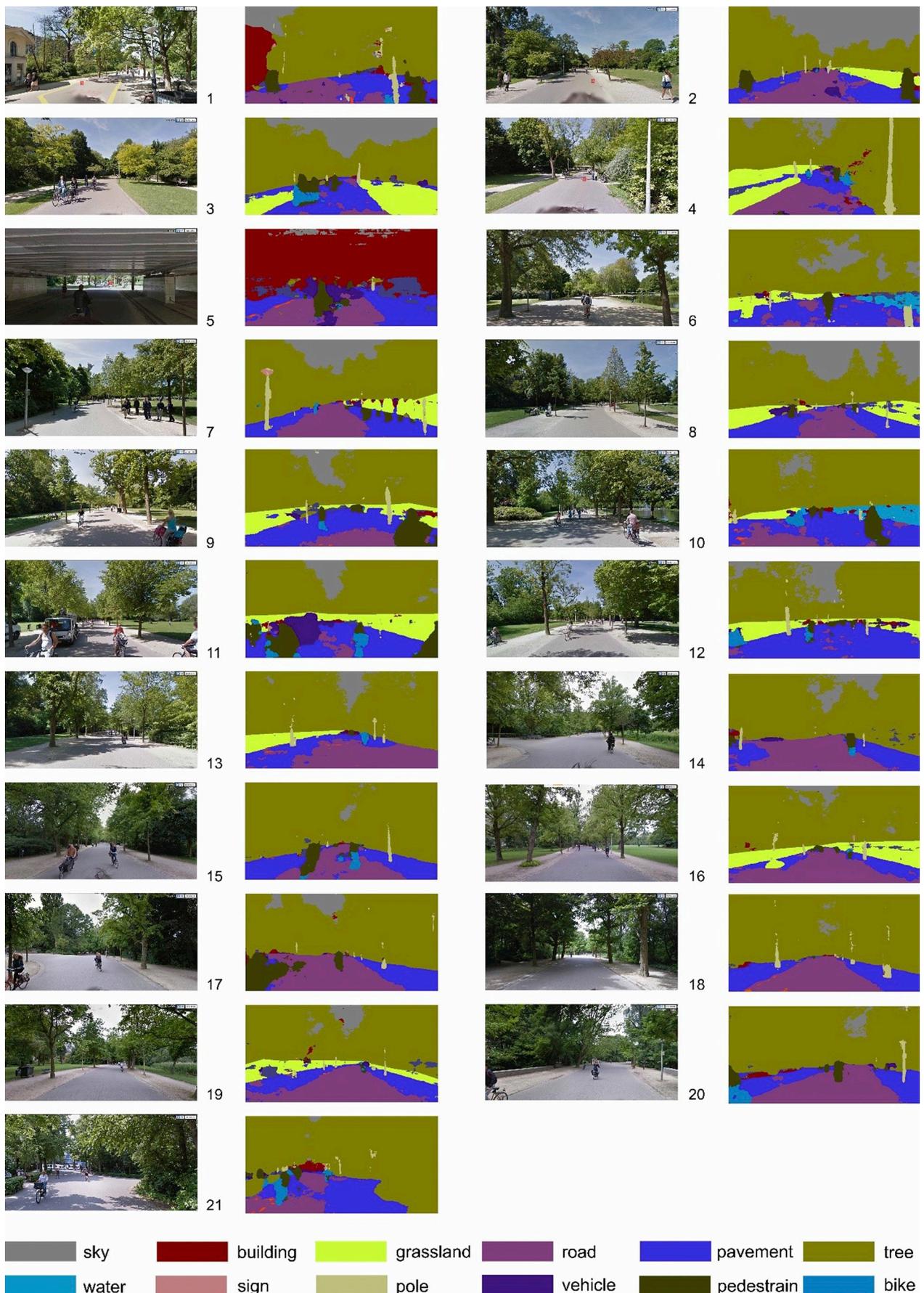
Fig. 9. SegNet analysis of 21 Scenes along Path 1 with an equidistance (100 m) (Photos derived from Google Maps Street View, February 2019).
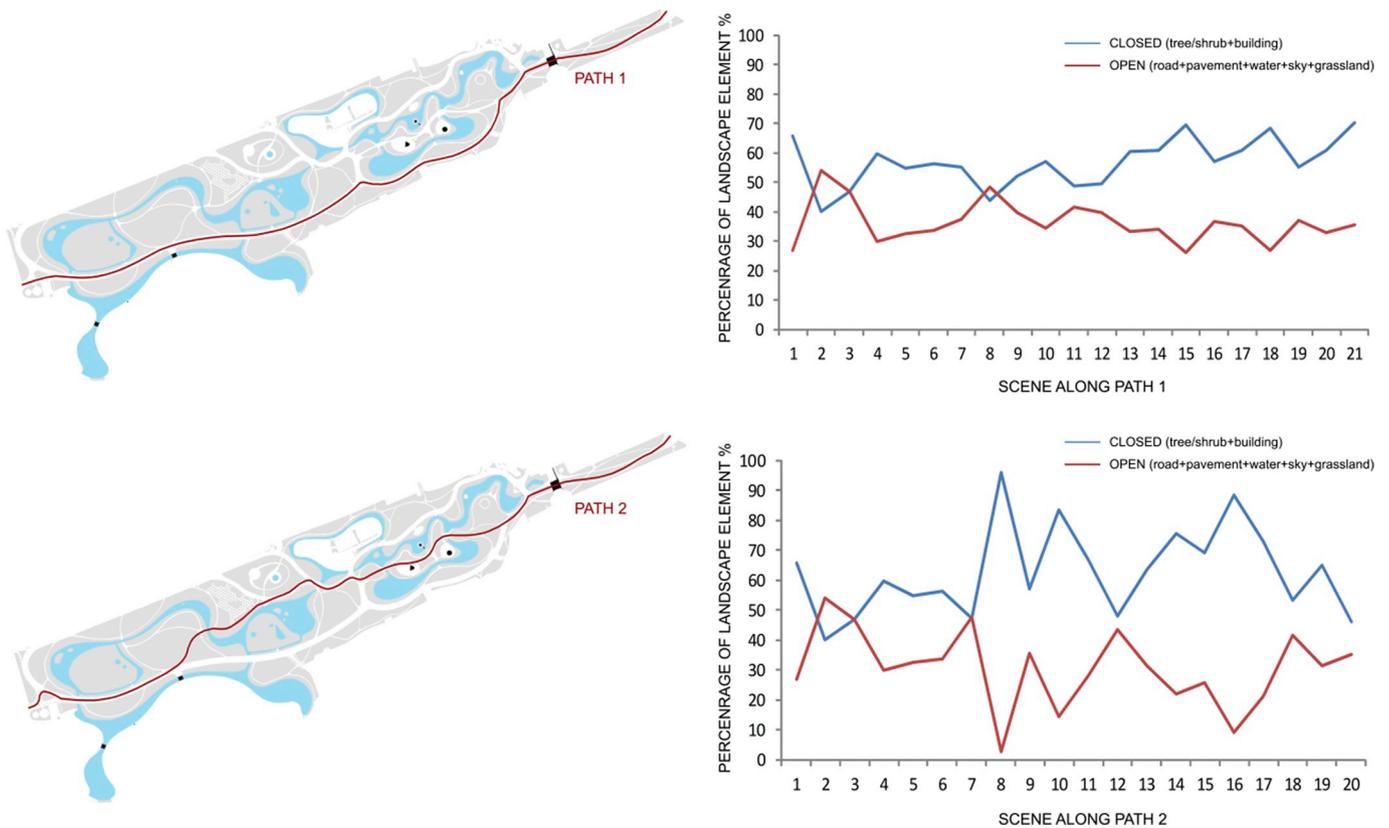
Fig. 10. Line charts showing the sequence of scene's degree of openness along Path 1 and Path 2 at eye level based on the SegNet results.

4.4. Visibility analysis

Visibility analysis is basically a three-dimensional calculation based on raster, which shows the geographical area visible from a given position (Nijhuis et al., 2011). From the observer's perspective, it maps all the points within the horizon and excludes the points that are obstructed. It also maps the visibility of features that refers to the area of an object that can be seen (Federal Highway Administration, 1988). The commonly used tool is GIS-based viewshed analysis in ArcGIS or 3D analyst (see, for example, Fisher, 1996; Llobera, 2003; Möller, 2006; Brabyn and Mark, 2011; Krøgli et al., 2015; Cuckovic, 2016; Kamalipour and Dovey, 2019).

Nijhuis (2015) proposes accumulative viewshed analysis as a way to analyse spatial-visual characteristics at eye-level along routes. Through people's eyes, each person experiences the environment by a moving sensory system, which refers to a viewer's head and body behaviour (Felleman, 1979). Moving speed, direction, transportation modes will influence the visibility of spaces (Daniel and Boster, 1976; Sanoff, 2016; Weitkamp, 2010; Nijhuis, 2011). Pedestrian activities can be approximated by a 360 degree horizontal viewing range. The visual angle of walking straightforward or jogging is defined as 124 degrees and cycling is about 60 degrees (Panero and Zelnik, 1979; U.S. Department of Transportation, 2015) (Fig. 12). Moreover, parameters for controlling the viewshed analysis also includes various factors, such as observation point elevation values, vertical offset (eye level height) and scanning distances (Esri, 2016).

A precise raster Digital Terrain Model (DTM) is constructed as a basis for the GIS-based viewshed analyses as presented in this paper. The DTM is based on the LiDAR scanned Digital Elevation Model (Actueel Hoogtebestand Nederland, accessed June 2018) and complemented with vegetation canopies and buildings derived from detailed field surveys. Two types of vegetation are included: above and below eye-level. Canopies above eye-level without sight block are neglected where only the area and height of trunks are included in the

DTM. Vegetation such as shrubs with dense canopies are included as solid mass.

4.4.1. Orientation

The skeleton of the park is determined by a series of spaces that follow a linear configuration. The path system connects the spaces. Three important routes are used to perform a cumulative visibility analysis. As visible in Fig. 13, different transportation modes show clear differences in visible space, when the moving speed increases, the visual angle and the visibility diminishes. Directions of movement also influence the visible field. Analysis of Path 1 and Path 2 point out that the route in northeast to southwest direction provides more visible space than the southwest to northeast direction. Visible areas along Path 1 from northeast to southwest entails 13.72% of the total park area. The southwest to northeast direction only accounts for 5.72%. Along Path 3, there is more visible space by moving in a clockwise direction than counter-clockwise. The main entrance in the northeast side of the park, the Stadhouderskade-gate, takes full advantage of this effect, offering a spacious and grandiose glimpse into the park, drawing the attention of passing by pedestrian and pulling them into the park (see also section 4.1).

Yahner et al. (1995) argues that the direction of open views can give insight in the sense of spatial-visual orientation. An example is shown in Fig. 14. Here the sense of visual orientation by walking or jogging with a 124 degree horizontal vision from the northeast to southeast is evaluated. The spatial structure along the first half of Path 1 can be characterized as a series of open spaces with water features and grasslands along the north side of the route, while the visual orientation of the second half addresses both sides. Path 2 links most of the important facilities in the park (i.e. sculpture, stage, café, and pavilion), and require good accessibility and visibility. The spatial structure along this path is visually open and the entire route is part of the space it goes though. Path 3 is a circular beltway. The northeast part of the route has an inward visual orientation. The views are towards open areas with
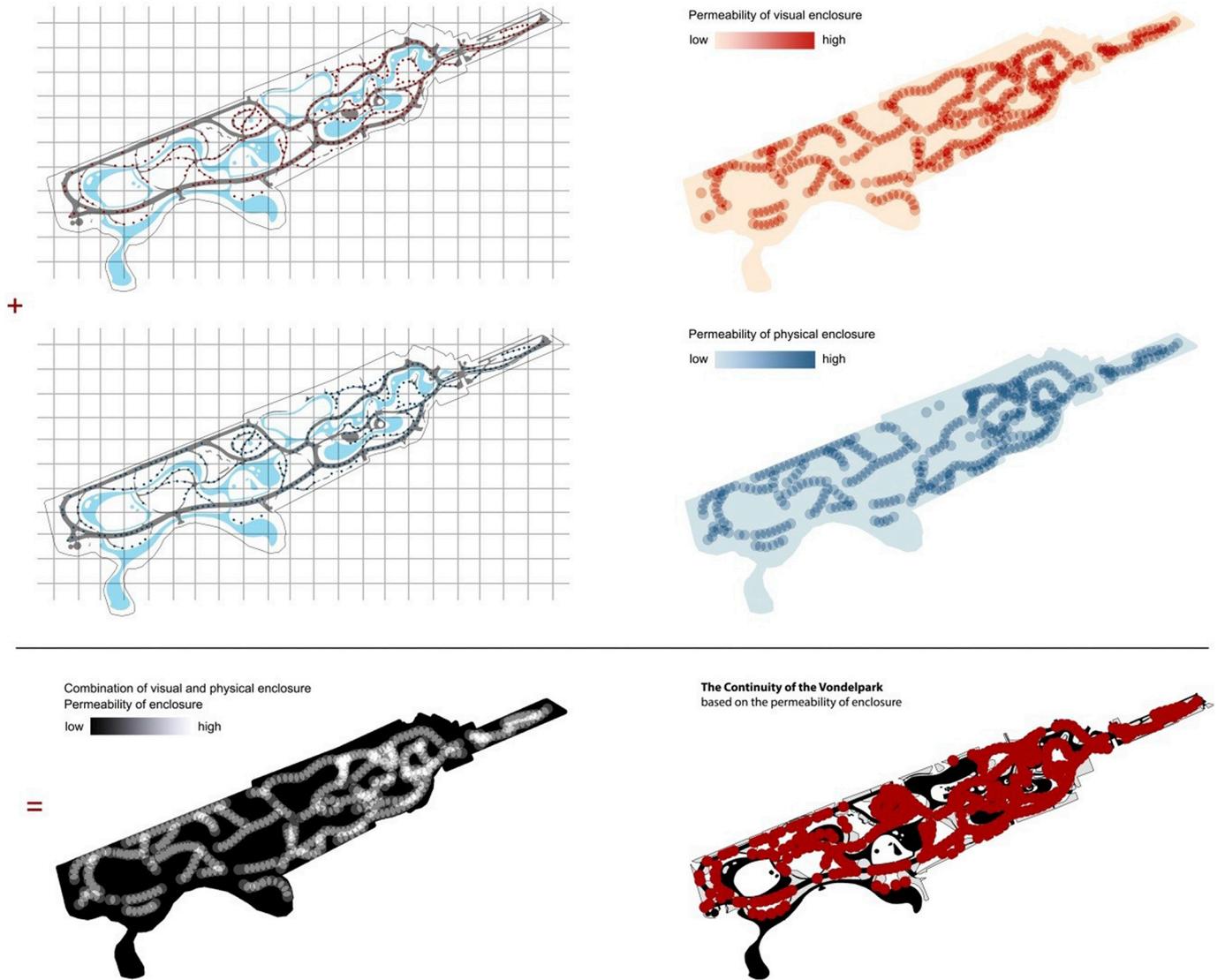
Fig. 11. GIS-based analysis of visual and physical densities of spatial thresholds indicating the continuity of space in the Vondelpark in 2019.

most of the ornamental and functional elements in the park. Due to the tall trees along the northwest part of the loop, there is tunnel-effect with a clear linear visual guidance.

In addition to the measurements along paths, a visibility analysis is applied on individual viewpoints to provide insights in their specific spatial function. For example, bridges play an important function in the spatial composition of the park. Four viewpoints were set up on each of the bridges and the visibility analysis reveals a particular spatial principle. That when people cross or stand on the bridge, the visual orientation follows the direction of the water which is perpendicular to
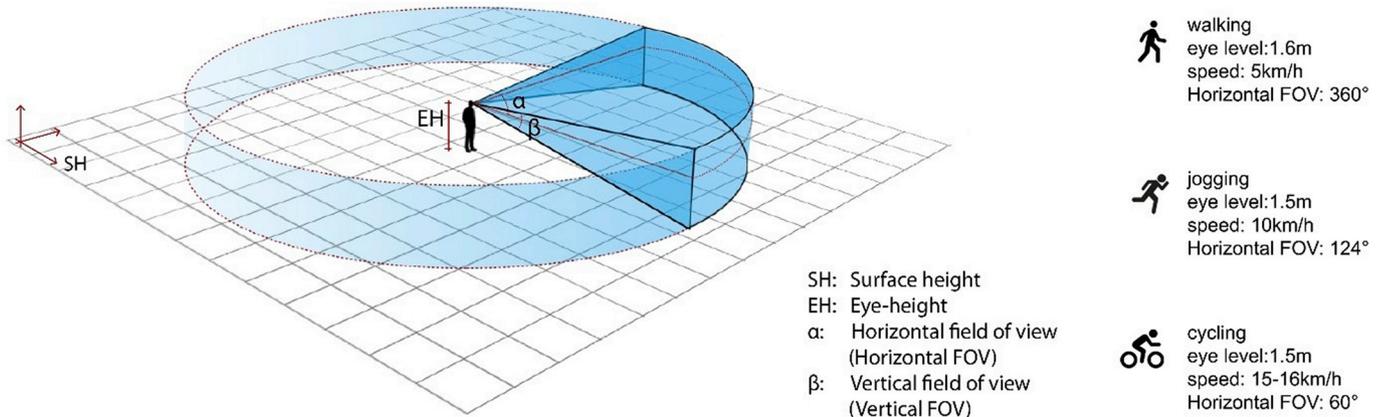

Fig. 12. Parameters for controlling the visibility analysis (Data derived from Panero and Zelnik, 1979; U.S. Department of Transportation, 2015).
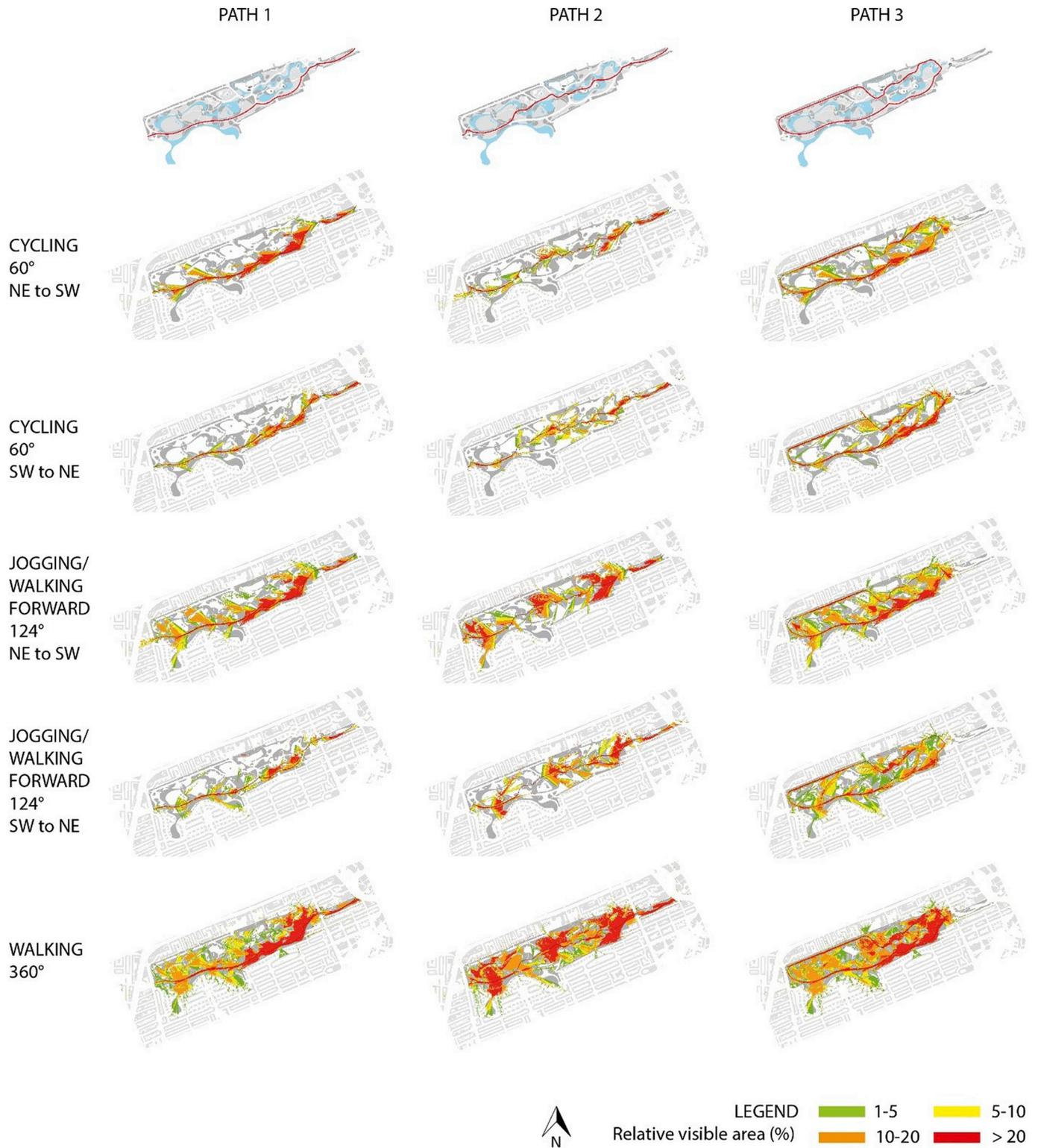
PATH 1　　　　　　　PATH 2　　　　　　　PATH 3

Fig. 13. Visibility analyses of Path 1, Path 2, and Path 3 simulating different transportation modes, speeds, viewing angles, and directions (See Supplementary Document for detailed images).

the orientation of the physical direction of the route across the bridge (Fig. 15).

4.4.2. Sequence

The accumulative visibility analysis can give also insight in the duration of visibility of spaces/The first half of Path 1 shows relatively open views compared to the other half. Bar charts are used to show

changes in duration of the visibility of each viewpoint, which indicates distinct flows of visual enclosure (Fig. 16). The perception of sequence along Path 1 mostly changes gradually from open to semi-open, while the sequential experience along Path 2 varies from open/semi-open to enclosed sharply and repeatedly.

The visibility analysis can also provide insight into the visual dominance of different forms of land-use (Nijhuis, 2015). Along the two
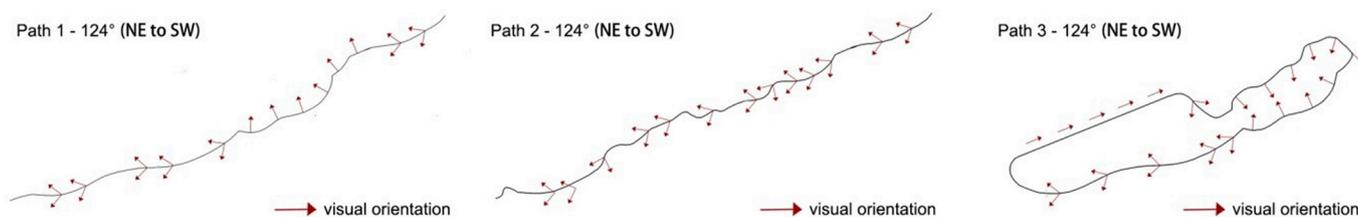
Fig. 14. Analysis of the inward-outward visual orientation along the three paths.

paths, grassland and water are visually dominant (Fig. 17). There are more buildings visible from Path 2 (0.30%) than from Path 1 (0.22%), while the visibility of water from Path 2 (21.65%) is less than from Path 1 (24.31%). To sum up the visual landscape from Path 2 more related to architectural features and offers a high degree of variation in openness. Path 1 provides more distinct open views dominated by natural features.

As mentioned before, the horizontal visual range corresponds to how much can be seen, while vertical viewing angles are crucial for the sense of distance and appearance of objects in terms of spatial-position relationships (Nijhuis, 2015; Maertens, 1877; Higuchi, 1988). The foreground, middle ground, and background are mainly determined by vertical visual angles and the length of the sightline (Tveit, 2009). Higuchi (1988) proposes the foreground to range from 10 to 30 degrees facing downward. Except when one is standing on a high building or terrain elevation, then the sense of foreground and the middle ground becomes a matter of vertical distance. Views between 0 and 10 degrees below the horizon are defined as middle ground, whereas the area from 0 to 9 degrees facing upward are considered visually as the background. People focalizes sight line mostly within the middle ground range (Fig. 18). Also, the sense of pictorial view (multi-layers of the scene) relates to the distance between the viewpoint and the spatial structures (Lange, 2001), which is elaborated as background- scene (more than 5 km), middle ground-scene (between 400 m and ca. 5–8 km), and foreground-scene (0 to 500–800 m).

4.4.3. Complexity

Including vertical angles in the visibility analysis demonstrates the complexity of spatial-visual landscape compositions. In an open space, when a viewer looks at a specific object from different locations, this could provide various visual effects and perceptions. For example, a particular statue in the Vondelpark (Joost Van Den Vondel) has round-shaped flowerbeds higher than ground level and is one of the most popular foci in the park (Fig. 19). When looking at the statue from Viewpoint 1, the foreground has an open and undulating grassland. A church outside the park (Vondelkerk) and the vegetation edges are the background in this scene. In Viewpoint 2, the foreground is determined

by grassland and the path itself. Water bodies play an important role as the middle ground reflecting the features from the background. The sculpture, the flowerbeds, and the vegetation skyline are now visually in the background. This example points out that position of the observer to the landscape space (and featuring elements) is of crucial importance and that changes in position have a great impact on the perception of spatial diversity.

Visibility is an integrated three-dimensional mapping method that considers various relevant factors from an eye-level perspective, in order to extract people's visual perception of the landscape. This measurement can easily show different visual clues of spatial compositions and configurations, such as sequence, visual orientation, and complexity. These are crucial for interpreting and evaluating all kinds of spatial-visual landscape design intentions.

4.5. Landscape metrics

Landscape metrics are important methods for characterizing landscape structures (Uuemaa et al., 2009). They are originally developed for the spatial analysis of land-use patches in landscape ecology, in which landscapes are modelled into patches, corridors, matrix and mosaics (Nijhuis et al., 2011). Software packages like FRAGSTATS developed by McGarigal and Marks (1995) and GIS-based toolboxes (e.g. Patch Analyst and module Pattern) are widely used to quantify potential metrics for landscape compositions and configurations. Landscape metrics are two-dimensional measurements by raster or vector. Examples of applications landscape metrics in visual landscape research can be found in Palmer (2004), Sang et al. (2008), Uuemaa et al. (2009), Lausch et al. (2015), and Zhang et al. (2019).

Landscape metrics such as Radius of gyration/Correlation length (GYRATE) and Proximity (PROX) (Table 2) are regarded useful to analyse the continuity of landscape space (McGarigal and Marks, 1995). Radius of gyration is a measure of patch environment, presenting how far across the landscape can a patch extend its reach. With this in mind, elongated and less compact extensive patches has a greater radius of gyration, which indicates the connectivity of spaces. In the design context, continuous spaces that are well connected together show
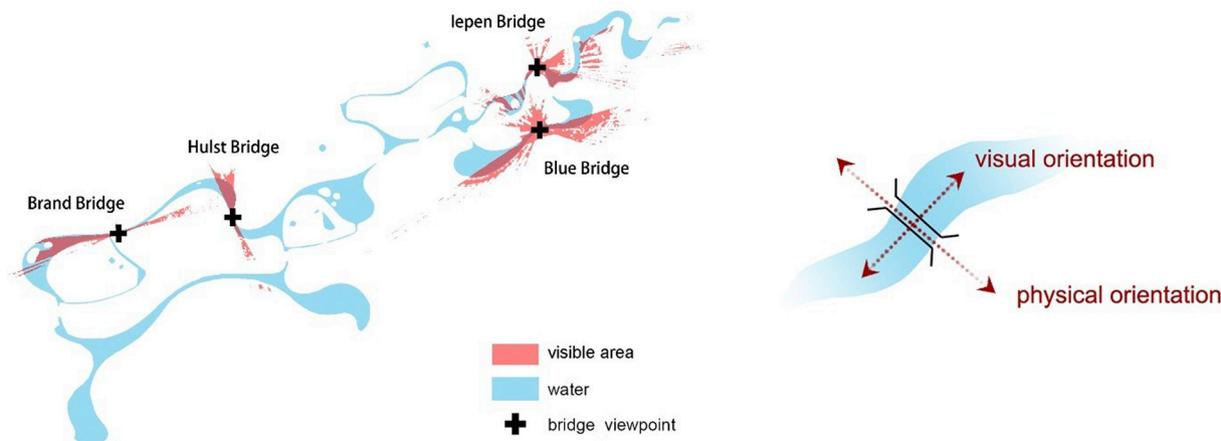

Fig. 15. GIS-based visibility analysis showing the relationship between the visual and physical orientation in Vondelpark.
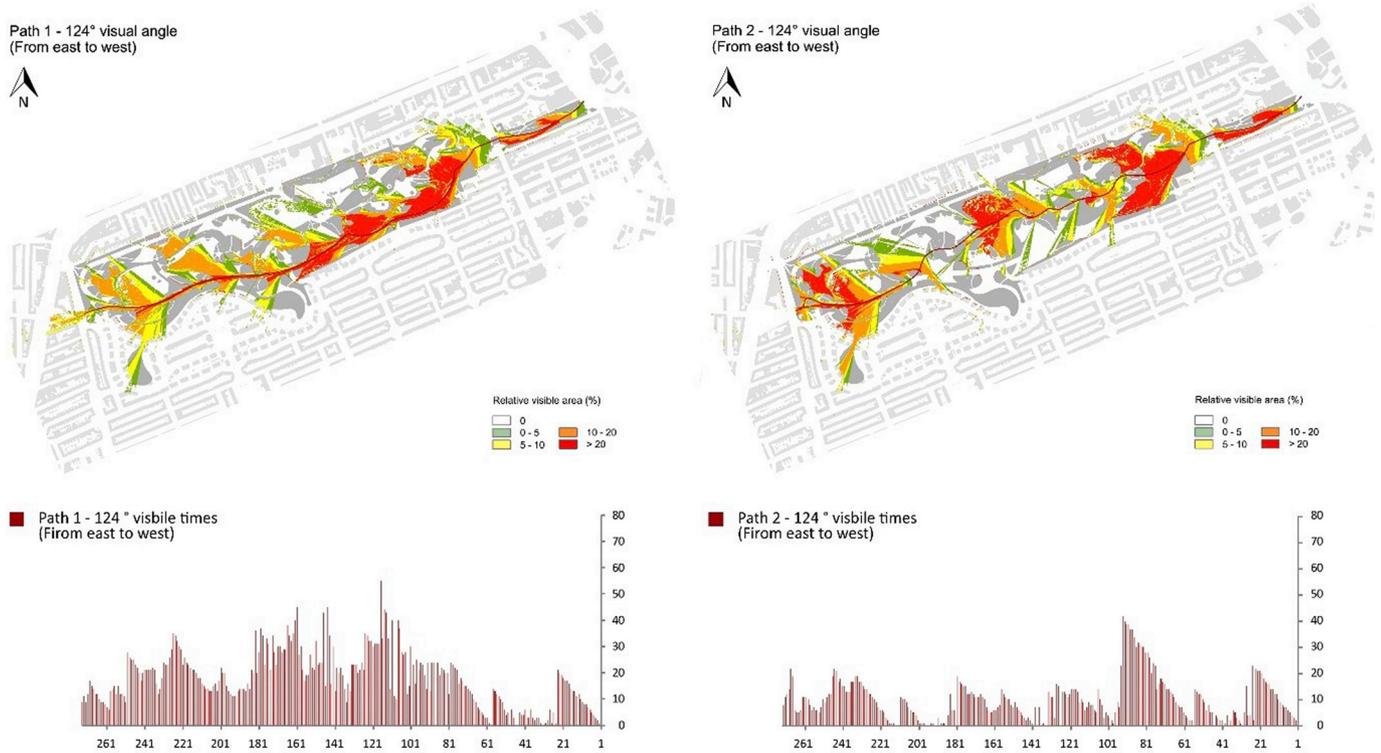
Fig. 16. Duration of the visibility of the spaces along paths 1 and 2 from east to west.

strong continuity and have a high Radius of gyration value. The Proximity index quantifies the spatial context of a patch in relation to its neighbours of the same class. A larger Proximity index shows compacted groups of spaces, which have the potential to connect together to create physical and visual connectivity.

For the Vondelpark landscape metrics are calculated using FRAGS-TATS-software (McGarigal and Marks, 1995) in combination with GIS. For the calculation the land use map is transformed into a patch map (Fig. 20). The analysis points out that individual, but connected spaces have a high value of Radius of gyration, which indicates strong continuity (Fig. 21). Compared to compact but discrete spaces, continuous and elongated spaces are more connected. At the same time, the analysis of Proximity shows that strong enclosed spaces have larger values. This means that even though they are not visually connected, they are nearby and closely connected in structural terms. Landscape architects can use these clues as basis to create continuity, such as providing transitional spaces or thresholds between contiguous spaces.

To summarize, here landscape metrics are used to analyse spatial-visual configurations relevant to spatial design. Indices to analyse patch, class, and landscape elements proof to be useful in analysing and representing specific spatial-visual characteristics of landscape space. As such landscape metrics offer means to address specific aspects of landscape space from a vertical perspective and complementary to the other discussed methods.

4.6. Eye-tracking analysis

Eye-tracking is used to record eye movements and fixations when people are observing scenes. Eye-tracking is broadly used in visual perception research in the recent years (e.g. Dupont et al., 2017; Junker and Nollen, 2018). Compared to common landscape perception research methods such as in situ or photograph observations in combination with questionnaires, or in-depth interviews, eye-tracking analysis measures people's eye behaviours and the observation of landscapes more objectively (Dupont et al., 2014). There are two main types of maps can be potentially used for indicating people's attention in the landscape, which are heat maps or fixation maps. A heat map (or dynamic heat map video) displays focus points of observation and indicates dominant visual elements in the field. A fixation map (or eye-tracking video) catches and records eye movements which can visualize the visual queue and affordances for way-finding in a landscape scene (De Lucio et al., 1996; Massaro et al., 2012; Popelka and Brychtova, 2013; Ren and Kang, 2015; Junker and Nollen, 2018; Wissen Hayek et al., 2019).
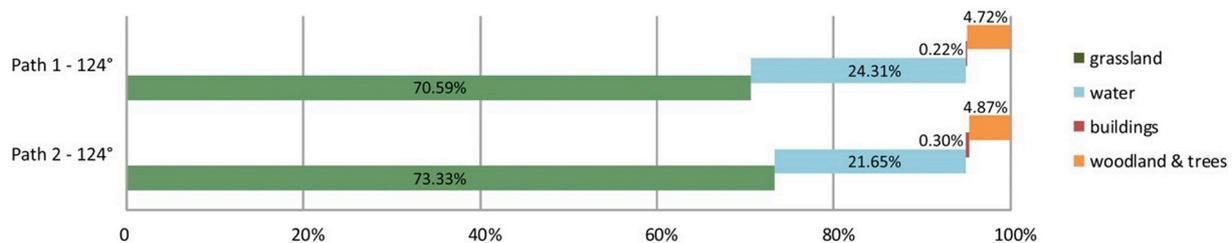

Fig. 17. Comparison of visual dominance at eye level from Path 1 and Path 2.
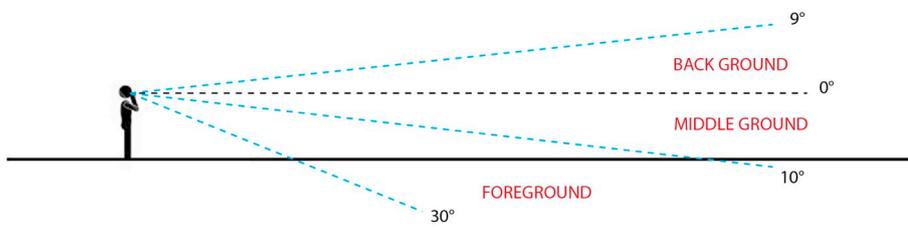
Fig. 18. Angles of elevation and sense of visual nearness in an open view (Data adapted from Maertens, 1877; Higuchi, 1988).

4.6.1. Complexity and continuity

In the Vondelpark three of the most important scenes are selected for eye-tracking analysis. The eye-tracking experiment involved a sample of fifteen people that observed photos of the scenes that were displayed at a one-to-one scale display. The results are accumulated and visualised in Fig. 22. The analysis reveals that monuments, water edges, the church tower, and specimen of trees (different colour or texture) are important visual elements that attract attention. The fixation maps give a more detailed view on the common visual logic of the scenes. The experiment results show that the relatively bright, contrasting and distinctive elements (e.g. landmark, open space, or specimen trees) raise the attention first. Then the eye follows gradually the contour lines of the foreground, middle ground, and background (skyline). To

conclude, by having an overview of the landscape, people tend to discover and predict where to go next. The most bright and distinctive elements in the landscape space are considered to be visually the most attractive hence their potential to facilitate orientation and afford further action.

4.6.2. Sequence and orientation

Eye-tracking analysis was also applied to a sequence, a set of eye-level photographs taken on viewpoints with an equal distances of 50 m along Path 1 (Fig. 23). The accumulated results shown in the heat maps reveal that elements along the path, like streetlamps, benches, and different textures of vegetation are the main focal points. However, open views with water, grassland, etc., and thresholds, such as branches
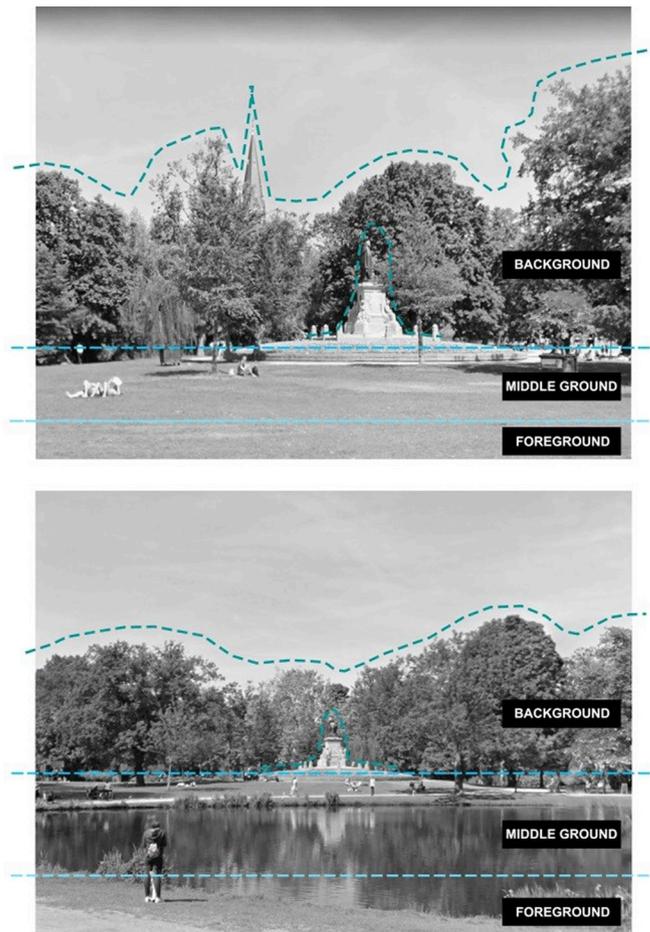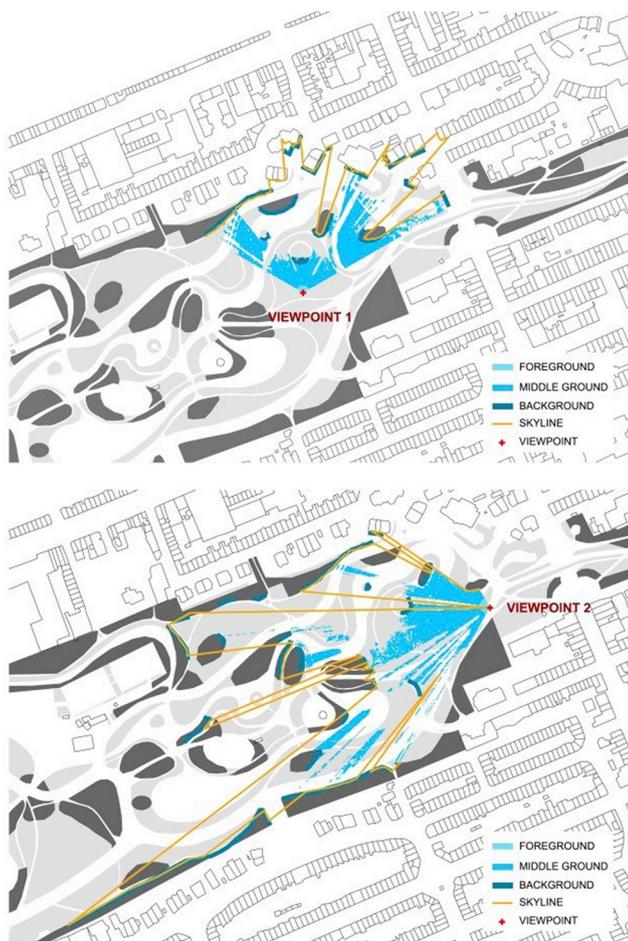

Fig. 19. Visibility analysis showing the diversity (complexity) of scenes with the composition of different foregrounds, middle grounds, and backgrounds in Vondelpark (Photos collected from Google Maps Street View, February 2019).

Table 2
Landscape metrics related to spatial continuity (McGarigal and Marks, 1995).

Indicator	Abb.	Scale	Spatial description	Formula	Variable
Radius of gyration/ Correlation length	GYRATE	Patch	Elongated and less compact extensive patches have a greater radius of gyration, which indicates the connectivity of space.	$GYRATE = \sum\limits_{r=1}^{z} \frac{h_{ijr}}{z}$	h = distance (m) between cell ijr [located within patch ij] and the centroid of patch ij (the average location), based on cell center-to-cell center distance. z = number of cells in patch ij.
Proximity	PROX	Patch	Patches in relation to its neighbours of the same class. The larger the index value, the more contiguous and higher the potential to connect.	$PROX = \sum\limits_{s=1}^{n} \frac{a_{ijs}}{h_{ijs}^2}$	a = area (m²) of patch ijs within specified neighbourhood (m) of patch ij. h = distance (m) between patch ijs and patch ijs, based on patch edge-to-edge distance, computed from cell center to cell center.

of the path structure, gateways etc., and water features, are visually the most important in the sequences. This is logic because a person's line of vision mainly concentrates on the continuation of the route. Also the borders are scanned to provide more information and when there are distinct features like a landform or a different texture in vegetation the eye fixates a little longer.

Eye-tracking analysis is a powerful mapping method that provides opportunities to understand the correlations between the spatial intentions of the designer (conscious/unconscious) and reception by its users. It help to reveal the perception of landscape architecture compositions and helps to be more conscious about the functioning of space, way-finding, affordances, etc.

5. Discussion and conclusion

5.1. Mapping methods for understanding spatial-visual characteristics

As exemplified by this paper, mapping landscape spaces combines landscape architecture concepts, landscape perception approaches and mapping methods. Applications of different methods enable landscape architects to explore and visualize different spatial-visual characteristics of the designed landscape (Table 3). Horizontal three-dimensional mapping methods (i.e. 3D landscapes, visibility analysis, and eye-tracking analysis) provide complementary interpretations on visual properties to vertically two-dimensional methods (i.e. complement analysis and landscape metrics) which mainly concentrate on spatial attributes. Furthermore, mapping methods based on measurements, such as grid cell analysis, visibility analysis, landscape metrics, and eye-tracking analysis, offer more precise spatial-visual clues of landscape compositions than qualitative conventional mapping methods, like hand-drawn compartment analysis and 3D landscape visualizations. Considering that each mapping method has its own merits, it is crucial to combine horizontal-vertical, qualitative-quantitative methods to get a more comprehensive understanding of landscape spaces.

5.2. Potential application

Mapping landscape spaces contains both the creative and rational and synergize with different fields of knowledge. The mapping methods and tools shown in this paper enable landscape architects to understand and visualize landscape space from the horizontal and vertical perspective, as well as allow better understanding of spatial-visual landscape features in the design. There is a vast array of possibilities available to map landscape spaces that can be used in different circumstances.

Compartment analysis can be easily generated through field survey so as to understand contextual situations in renovation projects, such as the current spatial compositions and organization, transportation network, and site restrictions etc. In addition to be analytical tools, they are useful for designers to present spatial layouts intuitively and instantly, and then derive design proposals in the design stage. Furthermore, compartment analysis represented by axial maps reveals invisible spatial information from a holistic point of view. It can be used to evaluate and validate the connectivity of the roadway network and indicate the rationality of the spatial design.

3D landscapes is useful to simulate eye-level visual perspectives to interpret landscape spaces incorporating different media and tools. Hand-drawn sketches and photographs can be conveniently implemented for site analysis in order to show visual perception of the space. 3D landscape modelling can be seen as a strong visualization tool which help explore possibilities of the relationship between content and forms through design experiments.

The grid cell analysis is suitable for calculating indicators like density and complexity, as well as the proportion of different landscape elements from vertical and horizontal perspectives. As developed in this
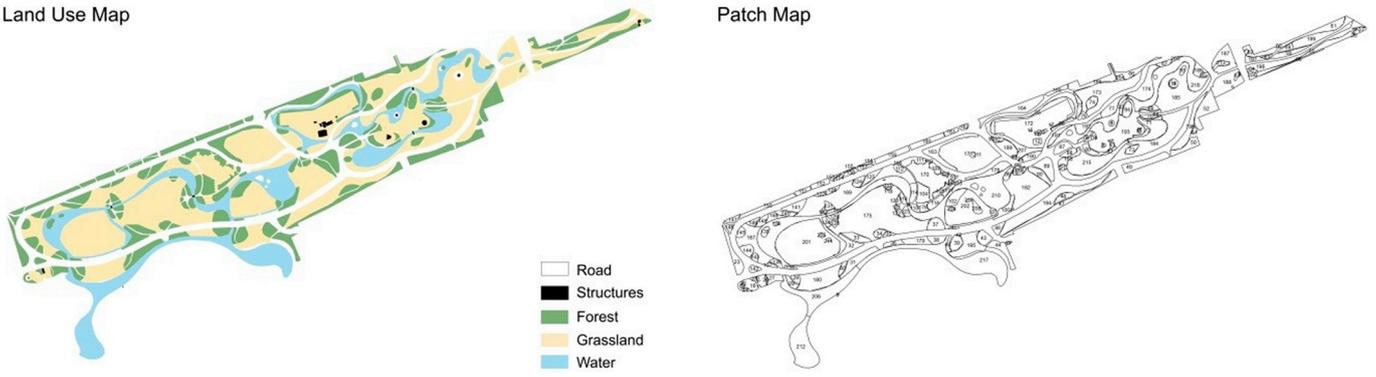
Land Use Map

Patch Map

Road
Structures
Forest
Grassland
Water

Fig. 20. Land-use map (left) and Patch map of Vondelpark (right).

research, the GIS-based mapping approach supports designers to comprehend spatial connectivity (visual/physical accessibility) of landscape spaces, which can be potentially used during the prophase analysis of design assignment or showing spatial effects of certain design schemes. SegNet is specifically used for analysing components from streetscapes. After adapting and applying to interpret spatial and visual landscape characteristics, it shows probability to give expression to dynamic sequential experience through movements either in the analytical or evaluation stage.

Visibility analysis can provide both dynamic and static visual information which enables to calculate either how many you can see or where you can see. The improved GIS-based viewshed analysis is to measure visible area and describe sequential experience through movements in the landscape, which is valuable to validate the visual performance of design plans. Moreover, considering vertical visual angles, visibility analysis is also possible to be used to interpret static

spatial and visual characteristics, such as pictorial effects of landscape scenes.

Landscape metrics is applicable to calculate and map spatial compositions and configurations from the ecological perspective via a combination of Fragstats and GIS platform. Only land use data (water, grassland, road, structure, forest) need to be concerned so as to build up and visualize the relationship between spatial patterns and ecological effects during the design process.

Eye-tracking analysis can be done by viewing photographs, models, or landscape scenes on-site, which aims to reveal how people perceive and observe landscapes. Either when people stop and perceive the landscape statically or move through the landscape, eye-tracking analysis can help capture typical, affordance, interesting, unique spot views, which is a good mapping method to explore whether subconscious visual behaviours fit descriptive design intentions.

FRAGSTATS
Radius of Gyrate
Correlation Length

High   Low

less connective

more elongated
not compact
more connective

FRAGSTATS
Proximity

High   Low
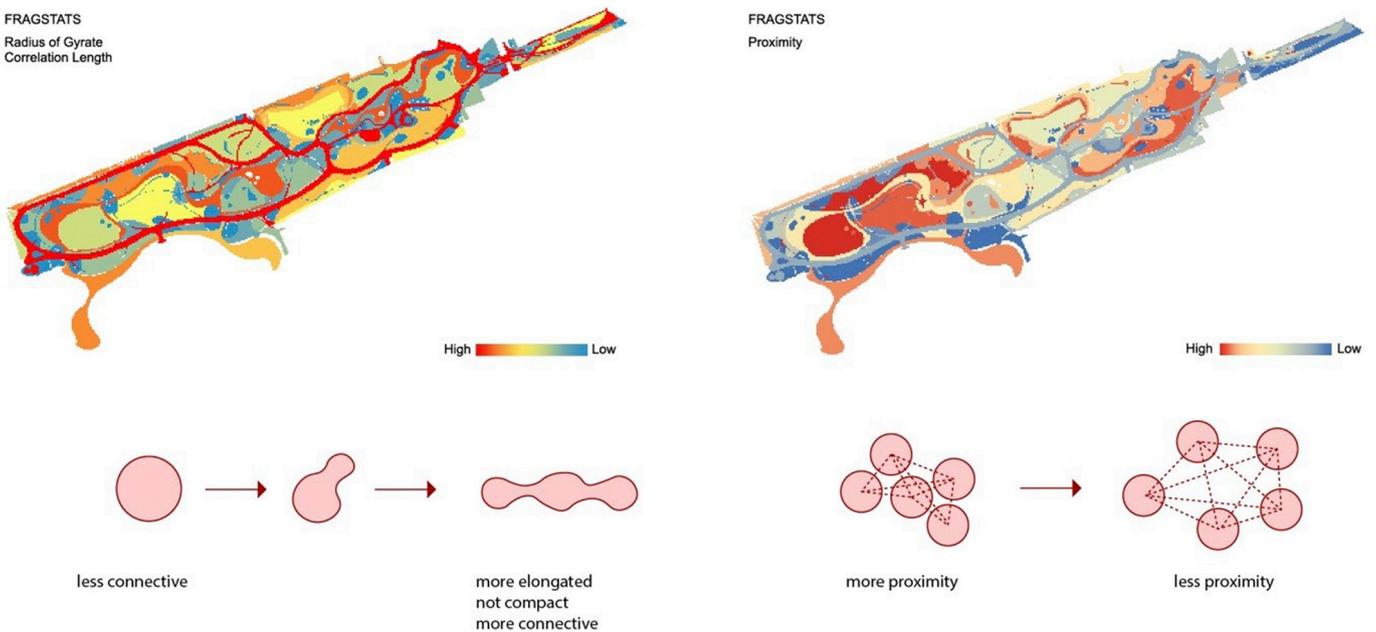
more proximity

less proximity

Fig. 21. Analysis of space using FRAGSTATS indicators: Radius of Gyrate (left) and Proximity (right) at the patch scale.
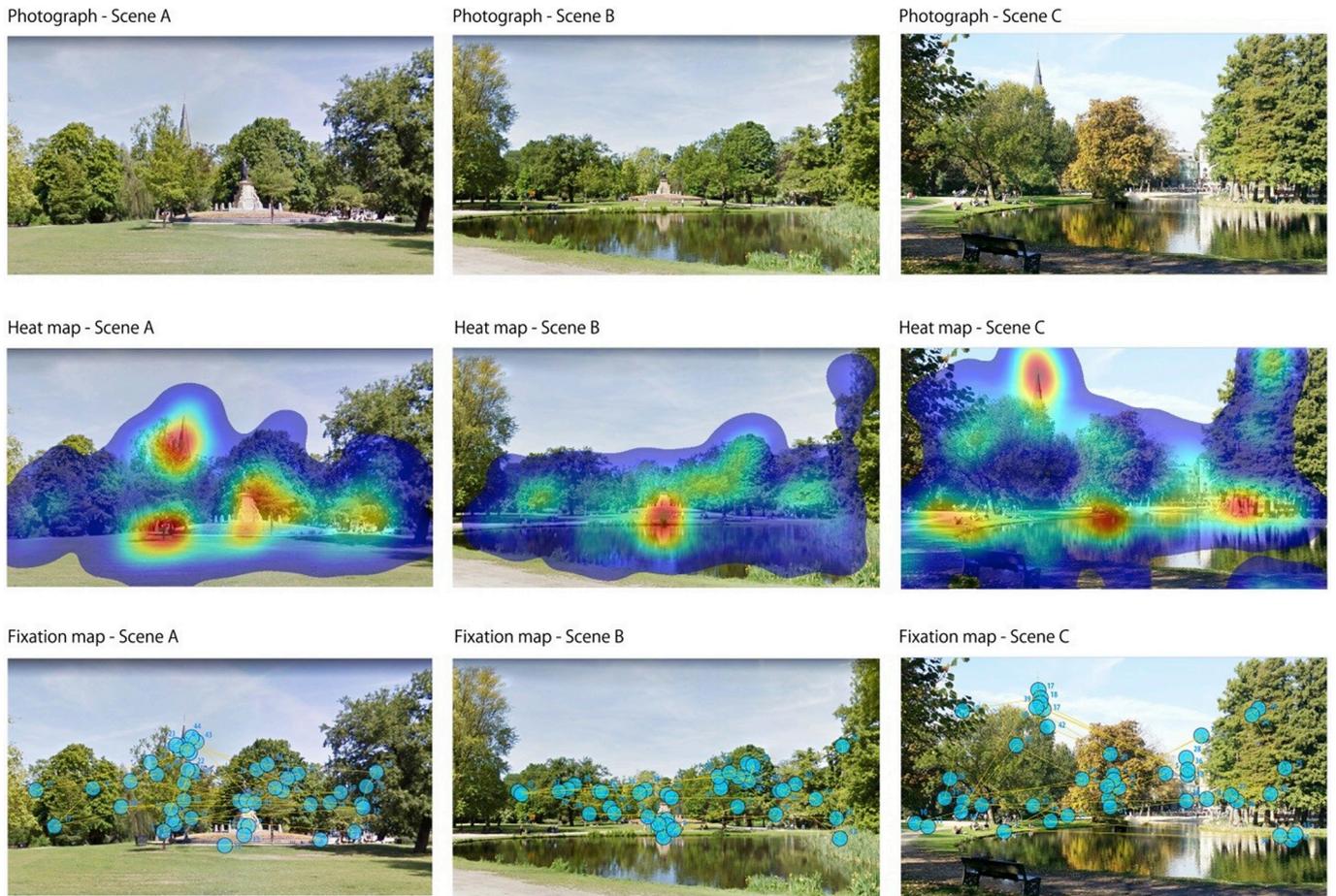
Fig. 22. Eye-tracking results visualised as heat and fixation maps for the analysis of static scenes (Photos collected from Google Maps Street View, March 2019).

5.3. Limitations

In order to understand and communicate about the spatial-visual characteristics of landscape architectonic compositions, mapping methods and tools addressing the arrangement of a variety of structural elements are of fundamental importance for landscape architecture. However, landscape design deals not only with form, but also with functional use and meaning to achieve social, cultural and ecological outcomes (Vroom, 2006). The mapping approaches as presented mainly focus on the spatial-visual aspects in designed landscapes, but do not take into meaning and symbolic aspects of landscape space, nor functional aspects.

The used mapping methods have also limitations in terms of data processing, and the results are depended on the quality of the data. For instance, even though the used Digital Terrain Model is a very precise raster dataset that includes all topographic elements (e.g. landform, build structures, vegetation, etc.), it has major restrictions in visibility analysis from eye-level, especially because it is hard to distinguish if vegetation canopies block sights or not. In that respect, using 3D-point cloud technology provides promising clues to achieve more accurate results. However, 3D-point cloud data processing and analysis requires high levels of processing capacity, which is still hardly possible in

practical terms. The grid cell analysis produced via SegNet platform also shows inexact identification of spatial components from photographs, which causes certain deviation for the further analysis. In addition, the results of eye-tracking analysis depends also on the size of the sample, in this case only fifteen respondents which is statistically not significant. The sample size will not only increase the accuracy of the findings, it will also have its effect on practical and organisational aspects, like how many eye-tracking devices one needs, processing of huge amounts of data. The next step would also be to include the dynamic aspects of spatial-visual perception using videos instead of static photographs.

5.4. Concluding remarks

This study provides an overview of methods used for mapping landscape spaces and their spatial-visual properties and explores ways for understanding designed landscapes in a more comprehensive and intersubjective way. The overview showcases mapping methods that have great potential to become part of the standard toolset available to landscape architects and related disciplines, and provides new horizons to interpret landscape spaces from a designerly perspective. The examples open a way to visualize and describe landscape spaces in

Sequential images of Path 1
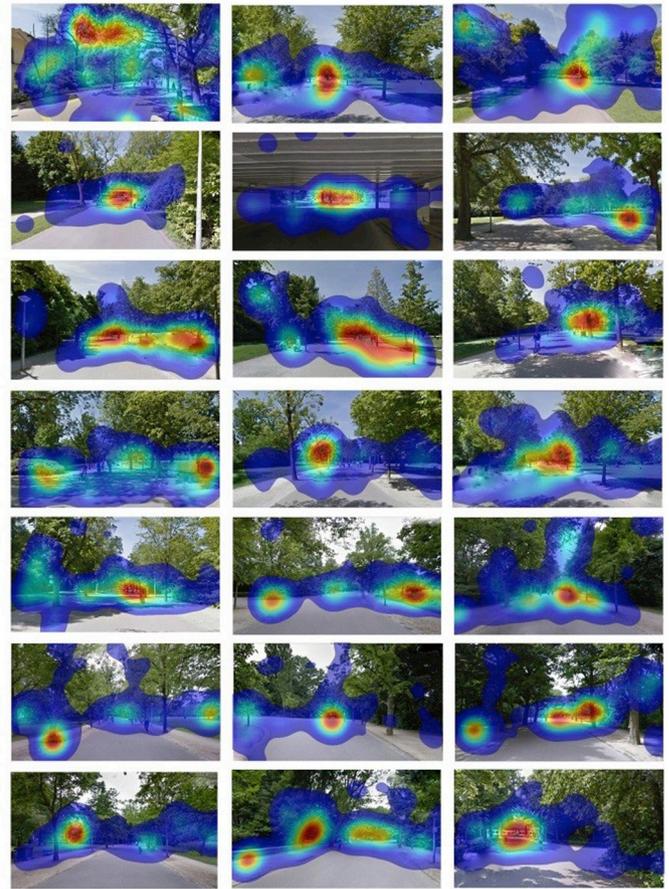
Heatmap from eye-tracking analysis

Fig. 23. Eye-tracking analysis of the spatial sequence along Path 1 in the Vondelpark, accumulated results visualised as heat maps (right) (Photos collected from Google Maps Street View, March 2019).

unconventional ways. As exemplified by this paper is there not one method or tool that can do it all, or can be regarded as a panacea. The power is in their combination. Each method has its own strengths and weaknesses and using them next to each enables to explore different aspects of landscape space in complementary ways. Important in this respect is not only to increase awareness on the potential of their use and the multitude of possible applications, but also to train future generations through educational programmes.

To sum up, studies on mapping spatial-visual characteristics contribute not only to an increased understanding of landscape space in the framework of design, but also offers clues for the development of the discipline by:

(1) *Supplementing the body of knowledge of spatial-visual aspects of landscape.* Mapping landscape spaces through analogue and digital methods enable landscape architects to gain insight in the form and functioning of landscape spaces in order to become more conscious about fundamental spatial-visual aspects relevant to landscape design.

(2) *Developing the toolbox for the interpretation of landscape spaces.* The overview showcases different mapping methods that address landscape space from horizontal and vertical perspectives and that in combination offer a wide range of possibilities to explore spatial features and visualize them. Measurements reveal inner mechanisms of spatial relationships and visual organization of landscape compositions. The quantitative mapping methods show great potential to understand, describe, and communicate landscape spaces in a more intersubjective way.

(3) *Adapting existing theories and techniques to investigate new perspectives for landscape design.* The mapping methods as presented in this paper integrates knowledge as developed in other fields, such as urban morphology and landscape ecology, and make them operational for landscape design.

This will help landscape architects to remain at the forefront of landscape development, transformation, and preservation while making use of new technologies, as well as traditional means for knowledge-based policy development and design interventions that take spatial-visual aspects as a starting point.

Table 3

The application of mapping different methods and tools on the interpretation of spatial-visual organization of landscape.[a]

Mapping method	Spatial-visual characteristics	Mapping tools	QUANT	QUALI	HORI	VERTI
Compartment analysis	Sequence: Width variation of the watercourse; Space, foci, threshold and the corresponding physical/visual relationships	Hand-drawn maps		O		O
	Orientation: Variation of the path shape; elastic direction of spaces	Hand-drawn maps		O		O
	Orientation: Connectivity/integration of paths (urban scale)	Axial maps (space syntax – Depth map)	O			O
	Continuity: Visual/physical openness of edge/space; integration of multiple spaces	Hand-drawn maps			O	O
	Continuity: Connectivity/integration of paths (local scale)	Axial maps (space syntax – Depth map)	O			O
	Complexity: Shape of the edge/space	Hand-drawn maps		O		O
3D landscapes	Sequence: Serial vision	Hand-drawn sketches	O	O	O	
	Sequence: Proportion of enclosure of a series of scenes	Photographs & SegNet (grid cell analysis)		O	O	
	Orientation: Visual/physical direction	Photographs		O	O	
	Complexity: Shape of space	Photographs		O	O	
	Complexity: Form of architectonic structures	3d models		O	O	
	Complexity: Vertical view angles, the foreground, middle ground, and background of the scenes	ArcGIS (visibility analysis) & Photographs	O	O	O	
Grid-cell analysis	Sequence: Proportion of enclosure of a series of scenes	Photographs (3D landscapes) & SegNet	O	O	O	
	Continuity: Density of visual/physical accessible points along path	ArcGIS	O	O	O	O
Visibility analysis	Sequence: Visible times of viewpoints on the path	ArcGIS & Excel	O		O	O
	Orientation: Visual direction	ArcGIS		O	O	
	Orientation: Relationship between visual and physical direction	ArcGIS		O	O	
	Complexity: Vertical view angles, the foreground, middle ground, and background of the scenes	ArcGIS & Photographs (3D landscapes)	O	O	O	
Landscape metrics	Continuity: Gyration of radius; proximity (patch scale)	ArcGIS & FRAGSTATS	O		O	O
Eye-tracking analysis	Sequence: Open space (water and grassland), volume (dominant element), and threshold	Eye-tracking software and hardware, photographs	O	O	O	
	Orientation: Open views and thresholds; characteristics of the path	Eye-tracking software and hardware. Photographs	O	O	O	
	Continuity: Open/bright points; Visual depth (foreground, middle ground, background)	Eye-tracking software and hardware, photographs	O	O	O	
	Complexity: Dominant elements; visual depth (foreground, middle ground, background)	Eye-tracking software and hardware, photographs	O	O	O	

[a] QUALI = qualitative; QUANTI = quantitative; HORI = horizontal; VERTI = vertical.

Author statement

Mei LIU, first and corresponding author, mainly contributes to conceptualization, methodology, software, validation, formal analysis, investigation, resources, data curation, writing-original draft and revision draft, visualization.

Dr. Steffen NIJHUIS, second author, mainly contributes to conceptualization, methodology, providing data and resources, supervising project, writing-original draft and revision draft.

Declaration of competing interest

None.

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Appendix A. Supplementary data

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