Uncovering the Visibility of Blue Spaces: Design-oriented Methods for Analysing Water Elements and Maximizing Their Potential

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Abstract: Existing studies indicate that a direct view of aquatic elements benefits well-being, and houses with blue views are often associated with higher prices. Therefore, developing analysis and design methods for visibility research of blue spaces are crucial to advance spatial design practice. Especially digital methods for analysing blue visibility and their potential in design still need to be identified and explored. This study explores the application potential of some powerful digital visibility analysis methods for blue space design. Specifically, this research first provides an overview of potential methods for analysing the visibility of water. Next, two practical design-oriented digital methods are briefly elaborated and illustrated by cases in Rotterdam (the Netherlands). Meanwhile, the study explores how the analysis results support spatial design practice. Last, the study discusses the potential of integrating blue visibility analysis methods into the iterative design process and makes prospects for future research.

Keywords: Digital visibility analysis methods, Isovist analysis, segmentation analysis, landscape design, evidence-based design approach

1 Introduction

With the prevalence of chronic lifestyle-related diseases and rapid urbanization, health issues have received increasing attention. The health benefits of natural environments as a practical solution to current health issues have been widely recognized, especially for green spaces. Recently, the health benefits of blue spaces have been identified, and many studies suggest that a direct view of aquatic elements (e. g. rivers, lakes, and oceans) benefits psychophysiological states and reduces stress (GRELLIER et al. 2017, HARTIG et al. 2014, ZHANG et al. 2022). Houses with blue views are associated with higher attractiveness and price (QIANG et al. 2019). Therefore, it is necessary to consider blue visibility in spatial planning or design process of urban environments, which could provide multiple benefits. On the other hand, current studies mainly focus on combining blue visibility with health data to explore the relationship between them for developing health evidence. However, only limited studies focus on integrating this health evidence into practical spatial design or policymaking, especially in guiding the design processes, which could be regarded as a huge vacuum in the existing research (ZHANG et al. 2022).

Knowledge/evidence-based design approach and design research provide a solid foundation and potential for filling this vacuum, as well as extend scientific understanding of design processes that were previously regarded as a black box (JONES 1992, OZTURK 2020). Specifically, spatial design is a core activity in landscape architecture and its related disciplines to provide solutions for urban or rural areas to achieve desired social, cultural, and ecological outcomes (NIJHUIS & DE VRIES 2019). According to the ASE paradigm, design could be regarded as an integrative practice consisting of three interrelated phases: analysis, synthesis,

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and evaluation. In these three phases, blue visibility analysis methods could be applied to the analysis and evaluation phases to identify site limitations and potentials of design proposals, as well as provide solid support for assisting designers in the synthesis phase. For designers, the integration and utilizing of these methods, especially innovative digital ones, have greatly aided the spatial design practice (LIU & NIJHUIS 2020a). In other words, these methods can help translate and apply research evidence in the design practice. However, only a limited number of studies have offered some available methods or tools to analyse the visibility of blue spaces and explore their design potential (LIU & NIJHUIS 2020b, NIJHUIS, 2011). To sum up, there is a need to identify practical digital visibility analysis methods that support design research and design for the development of effective blue spaces in the urban environment.

This paper aims first to provide an overview of potential methods for analysing the visibility of water from a design perspective. Also, two practical design-oriented digital methods are briefly elaborated and illustrated by cases in Rotterdam (the Netherlands). The paper ends with a discussion on the potential of integrating blue visibility analysis methods into the iterative design process and provides an outlook for future research.

2 Methods

2.1 Digital Methods for Analysing Blue Space Visibility

Reviewing the current research and practice on landscape visibility, there are six representative practical methods suitable for analyzing blue visibility, including the statistical index approach, (Cumulative) viewshed analysis, (3D) Isovist analysis, segmentation analysis, eye-tracking analysis, and 3D landscape analysis (HELBICH et al. 2019, KIM et al. 2019, LIU & NIJHUIS 2020b, NIJHUIS 2015, PALMER 2022a and 2022b, PUSPITASARI & KWON 2020). Specifically, the statistical index analysis uses alternative indicators, such as the number, total/ mean area, or density, to measure blue visibility. It is mainly applied in spatial design projects at the regional scale and contains the advantage of simple and rapid calculation. (Cumulative) viewshed analysis adopts the continuous digital landscape model to calculate and visualize the surfaces that are visible to specific observer features. Since it is integrated into GIS software, it could be applied in regional/intermediate projects where computing power is sufficient. Due to the input data and used analysing tools, the way in which the above two methods are integrated into the design process to assist design decisions is to allow comparison of changes pre/post spatial design interventions. On the other hand, (3D) isovist analysis shares a similar calculation logic with viewshed analysis, while the precision and ease of modelling allow it to be applied to projects at the individual scale by simulating blue visibility changes during people's movements. Segmentation analysis and eye-tracking analysis both borrow the theory or techniques from computer vision to describe the visibility of blue space at the individual scale through the analysis of characteristics in specific scenes quantitatively. The eye-tracking analysis attempts to describe people's perception of blue spaces more objectively by measuring observers' eye movements and associating them with spatial characteristics. Last, 3D landscape analysis is widely used in designers' daily practice to identify the characteristics of specific spatial arrangements using 2/3D visualisations (LIU & NIJHUIS 2020b). Unlike the two blue visibility analysis methods at the regional scale, the four methods at intermediate/individual scales, when integrated into the design process, allow rapid simulation of the post-intervention scenario to help designers test and visualize different design intentions. Table 1 lists the existing blue visibility analysis methods with detailed information.

Table 1: Detailed information on different digital methods for analyzing visibility

	Description	Main Tools & Platforms	Input Data	Application Scale	Interactions with Design Process
Statistical Index Approach	Using some indicators (e. g. total or mean area) within selected units to describe the visibility of blue space	GIS, Excel	Land Use Map; Satellite Images	Regional Scale	Pre/Post-design Analysis
(Cumulative) Viewshed Analysis	Delineating the surfaces or areas which are visible to a set of observer features	GIS	GIS Raster	Regional/ Intermediate Scale	Pre/Post-design Analysis
(3D) Isovist Analysis	Similar to viewshed analysis, but with more emphasize on the polygon of visibility	Rhino & Grasshopper (3D), DepthmapX (2D)	Rhino 3D File; CAD Map	Intermediate/Individual Scale	Scenario-based Analyzing Tool
Segmentation Analysis	Describing the types and proportions of landscape elements in the field of view quantitatively	Python, Excel	Site Photos	Individual Scale	Scenario-based Analyzing Tool
Eye-tracking Analysis	Recording eye movements and fixations when people are observing scenes to obtain their perception	Eye-tracking hardware & software	Site Photos & Videos	Individual Scale	Scenario-based Analyzing Tool
3D Landscape Analysis	Using photos or digital models to describe the visibility qualitatively	Camera, Rhino, SketchUp	Field Survey; Photos; 3D Model	Intermediate/Individual Scale	Scenario-based Analyzing Tool

After reviewing the methods, it is important to assess their potential for integration into the design process and to select the representative and novel ones to demonstrate their application. There are four criteria to identify their potential in the design process. Specifically, the methods should first allow implementation in designer-friendly software. Most of the methods listed could be integrated and run in existing and easy-learning software environments, including GIS, Rhino, SketchUp, Photoshop, and Excel. Only the segmentation analysis needs to be run in Python directly via existing deep-learning packages and pre-training models, which may be unfamiliar to designers. Therefore, it is worth showing its application and discussing its design potential in this study. Second, the methods should be adaptive to the input data with multiple precision and sources. Since eye-tracking analysis relies heavily on user participation, the requirements for input data are relatively strict. In other words, it describes blue visibility subjectively from a non-designer's point of view and therefore is not included in this study. Third, the method should understand the eye-level visibility of blue spaces since it is closely related to spatial design rather than planning and is currently receiving growing attention. Accordingly, the intermediate/individual-level methods are selected, as the regional scale methods are closely related to landscape planning. Last, the methods need to be integrated into design iterations, allowing quick changes to represent and test designers' new ideas. Thus, the scenario-based methods indicated in the last column of Table 1 will be chosen. Based on the above criteria and the novelty of the methods, (3D) Isovist analysis and segmentation analysis are chosen in this research for investigation, and their design possibilities are examined.

2.2 Study Area and Materials

To show the application of the two selected methods, a part of the Rotte River in Rotterdam is used as the study site (Fig. 1). There are three reasons for choosing the Rotte River as the case. First, the Rote River is located in Rotterdam, the second largest city in the Netherlands, which is rich in blue space resources. Rotterdam's urban living is closely related to the water, and blue visibility plays an important role in the spatial design of the urban environments. Second, the Rotte River used to be a major transport artery of the city in the past, and industrial products and vegetables were taken to the markets and auctions via it. Nowadays, the Rotte River has been transformed into a public space which is closely related to the daily life of the public and provides multiple benefits. Last, as an essential urban river in Rotterdam, data availability and physical accessibility (i. e. field survey) helped to evaluate and refine the results of method applications.

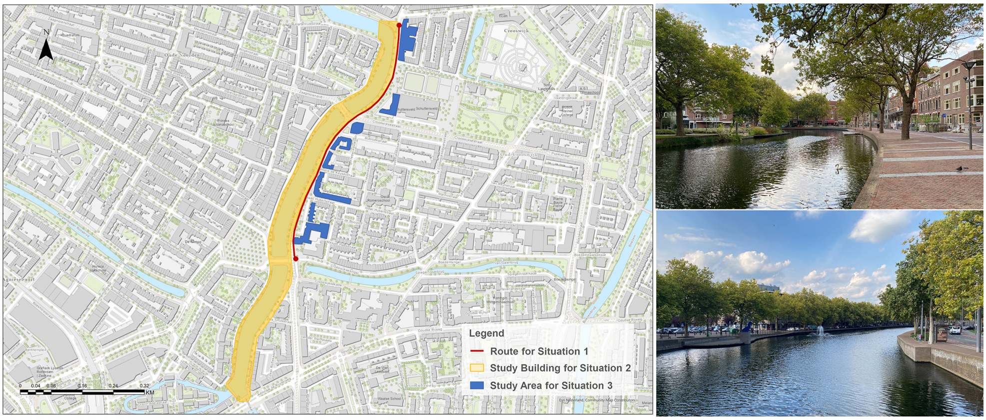

Fig. 1: Study area alongside the Rotte River in Rotterdam Center

As mentioned above, two methods for analyzing blue visibility are used to show their applications and explore their design potential. Considering that each method has its unique characteristics, Table 2 lists the details of the tools and data required for the two methods.

Table 2: Details of the tools and data used in the two selected methods

Analysis Methods	Tools	Input data
3D Isovist Analysis	Rhino 7; Grasshopper; Excel; ArcGIS Pro	3D model of the study area (Source: Rotterdam 3D & Gemeente Rotterdam; BGT Database; Field Survey)
Segmentation Analysis	Python; Excel; ArcGIS Pro	Site photos (Source: Field Survey)

3 Results

Three situations are presented to illustrate the application of the two methods and the design potential of their analysis results. Specifically, route-based visibility analysis adopts the 3D Isovist analysis method to calculate the visibility of water bodies under people's movements. Building-based visibility analysis also adopts the 3D Isovist analysis method, taking the building as the analysis object to calculate the visible proportion of blue space in different areas of the building surface. Moreover, the segmentation analysis method is incorporated into scene-based visibility analysis to obtain the visual features of typical scenes in selected area.

3.1 Situation 1: Route-based Visibility Analysis

3D Isovist analysis is used in route-based visibility analysis via Rhino-Grasshopper environment to calculate the water visibility of people alongside the specific route (Fig. 2). The process consists of the following steps: (a) divide the selected route into several parts; (b) generate original view sphere based on horizontal and vertical FOV (field of view); (c) construct and compute the Isovist Rays by setting the obstacles and analyzing radius; (d) calculate the proportion of Isovist Rays contacting the water surfaces for each part of the route; € visualize the analyzing results into chart diagrams. Three transportation modes, including walking, jogging, and cycling, and two directions, including North-South and South-North, are conducted in the calculation, and detailed analysis parameters are shown in Table 3.

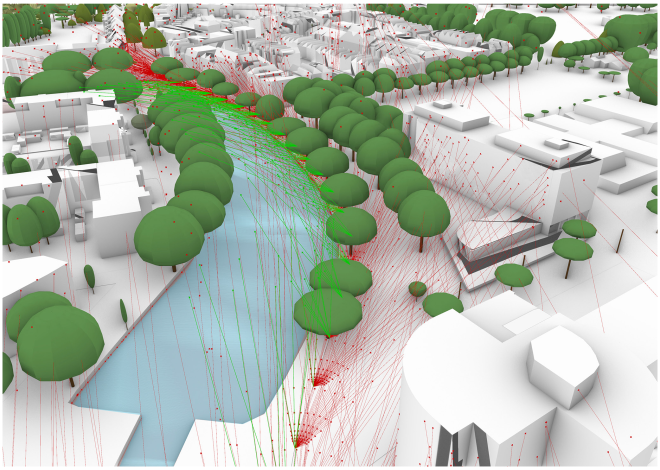

Fig. 2: 3D Isovist analysis in Rhino-Grasshopper environment

Table 3: Parameters of route-based visibility analysis

No.	Parameters	Definitions
1	Viewpoints on the route	Each 15m one point, 50 points in total
2	Horizontal field of view and eye level (Walking)	Horizontal FOV: 360°; Eye level: 1.6m
3	Horizontal field of view and eye level (Jogging)	Horizontal FOV: 124°; Eye level: 1.5m
4	Horizontal field of view and eye level (Cycling)	Horizontal FOV: 60°; Eye level: 1.5m
5	Route direction	(a) From North to South (b) From South to North
6	Visible distance	200m

Figure 3 shows the analysis results, which can directly identify the changes in blue visibility alongside the riverside route during the different types of movements. Regardless of the movement directions and transportation modes, it is obvious that the northern section of the route shows lower blue visibility, while the southern section presents higher visibility. This may be caused by the higher density of vegetation on the southern section of the road. Moreover, combing with satellite images and fieldwork, some sub-sections of the route with inconsistent blue visibility can be identified to help the designer comprehensively understand the site situations, such as the blue visibility of sections 18-19 and 44-46 is significantly higher than the surrounding sections. Therefore, this analysis can provide evidence support for detailed vegetation design by comparing the differences in blue visibility caused by changing vegetation locations through simulations.

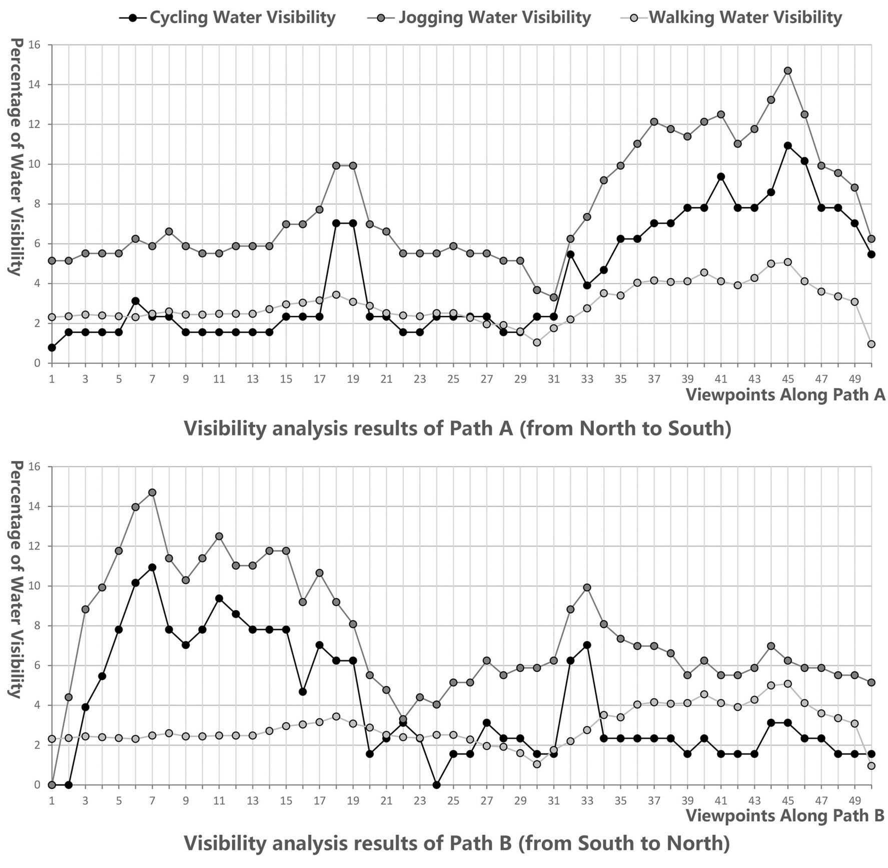

Fig. 3: Route-based visibility analysis results of two paths based on three transportation modes

On the other hand, during the movements on the selected route, the overall patterns of blue visibility among the three transportation modes are similar, especially for jogging and cycling. This could be due to the lack of clear route classification and design between the different transportation modes in the study area. Accordingly, the analysis can be applied to the planning and design of different routes by simulating the people's blue visibility of different traffic behaviours, such as the blue visibility of cycling routes at intersections could be lower to prevent distraction.

3.2 Situation 2: Building-based Visibility Analysis

Building-based visibility analysis also conducts 3D Isovist analysis to calculate the water visibility of building surfaces located near the Rotte River (Fig. 4). The analysis process consists of the following steps: (a) divide the building surfaces into the small matrix; (b) set the center point of each small cell as the input for 3D Isovist analysis; (c) conduct the 3D Isovist analysis as mentioned above; (d) calculate the proportion of visible water bodies in each cell of building surfaces; € visualize the results on buildings in an interactive way; (f) calculate mean blue visibility of each building and visualize it on map (optional). Detailed parameters for analysis are shown in Table 4.

Table 4: Parameters of building-based visibility analysis

No.	Parameters	Definitions
1	Size of Matrix for Dividing Buildings	1m · 1m
2	Max Visible Distance	300m
3	Size of Matrix for Dividing Water Surfaces	2m · 2m

The left graph of Figure 4 presents the analysis results directly on building surfaces, where the surfaces with blue-side colours indicate higher blue visibility. In comparison, the surface with red-side colours shows lower blue visibility. Even for the same building, the outcome interactively represents the varying degrees of blue visibility at different points. The blue visibility of two adjacent rooms can be varied, which may lead to completely different consequences, as ULRICH's (1984) famous experiment demonstrated that a ward with a natural view could have a positive influence on the recovery of the patients living in it. The result can help designers in architecture or vegetation design, in adjusting the layout of buildings or vegetation and repositioning the building windows or vegetation to increase blue visibility.

Fig. 4: Building-based visibility analysis results: Visualizing in Rhino (left) and summarizing on map (right)

On the other hand, the analysis results could provide evidence for planning and policy-making on the intermediate scale. Specifically, the study further calculated the average blue visibility of each building surface cell and visualized the results on the map. The results show that the middle three buildings have higher blue visibility, which provides the potential for evaluating the differences in blue visibility among several buildings (Fig. 4 [right]). This research merely uses a few riverside buildings for testing. In the future, the analysis can be extended to the buildings within a specific area to support the planning of neighbourhood spatial layout and strategies for pricing housing units.

3.3 Situation 3: Scene-based Visibility Analysis

The machine learning-based segmentation analysis method is used in scene-based visibility analysis. Following the procedures in HELBICH et al.'s (2019) research, the fully convolutional neural network for semantic segmentation (FCN-8s) model is trained by the ADE20K scene parsing and segmentation databases. A total of 208 photos taken based on the on-site investigation were used as input images for segmentation (Fig. 5). Next, the number of elements in scenes and the ratio of different element groups to total pixels are calculated.

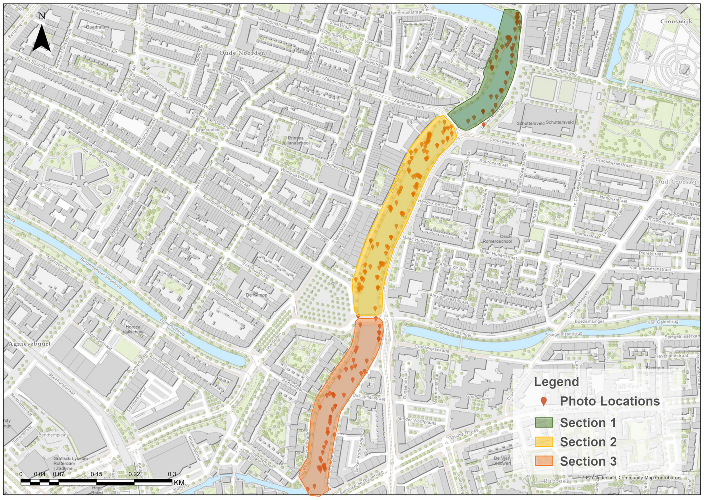

Fig. 5: Locations of photos and three sub-sections of the Rotte River

Fig. 6: The segmentation samples of typical photos of the Rotte River

Figure 6 shows the segmentation results of some typical scenes alongside the Rotte River. Areas with different colours on results represent different landscape elements in scenes, and the element composition of the scenes can clearly and directly be identified. Combining with digital modelling or photomontages, designers could adopt this method to analyze future simulations of typical scenes and visually compare the composition of key landscape elements and their positions in the simulations with the original situations.

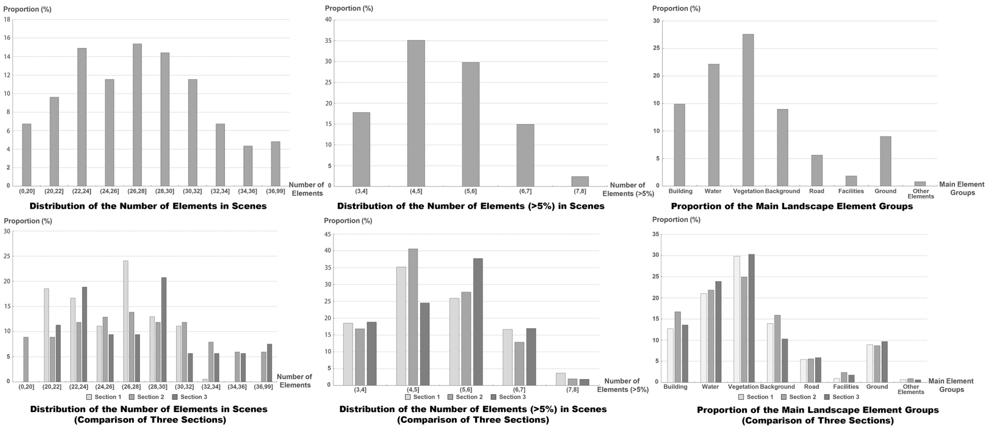

Fig. 7: The statistical analysis results based on the segmentation

On the other hand, the statistical analysis of the segmentation results can quantitatively describe the landscape element characteristics in scenes. The three graphs in the first row of Figure 7 demonstrate the distribution of the number of elements in each scene and the average proportion of area occupied by the main landscape element groups in all scenes. The number of elements in the current scenes is concentrated in 20-30, and the number of elements whose field of view accounts for more than 5% is concentrated in 6-9. Vegetation, water, and sky are the main landscape element groups, while facilities only occupy a limited proportion. The three graphs in the second row of Figure 7 compare the element characteristics of typical scenes among three sections of the river. From the results on the number of elements, the value in section 3 is higher than the other two sections, showing that it has relatively high visual complexity. The value of section 1 is more concentrated and less distributed in large values, demonstrating that its visual complexity is stable and relatively easy to understand. However, the value of section 2 presents more scattered patterns than the others, indicating that people's visual perception changes in this section are more significant. In addition, according to the results on the proportion of main landscape element groups, it is obvious that the proportion of vegetation in scenes of section 2 is less than in the other two sections, and the proportion of buildings is higher. More buildings in scenes could also prove that the visual perception of this section is dynamic and varied. Accordingly, segmentation analysis could be regarded as a powerful tool for designers to describe the landscape elements and the spatial-visual characteristics in design. Visual complexity, openness, naturalness and other indicators calculated by segmentation results can provide quantitative evidence for designers to compare different design schemes or intentions and then make final decisions.

4 Discussion and Conclusion

As exemplified by the presented applications, three situations of using two methods not only help to get a grip on the different characteristics of blue visibility of Rotter River, but also explore the possibilities in assisting multi-scale spatial design to improve it. In other words, two practical and design-oriented digital methods, including (3D) Isovist analysis and segmentation analysis, could facilitate a comprehensive understanding of the site's restrictions, limitations, and potentials on blue visibility, and provide clues for future design interventions. On the other hand, these methods are complementary and can be combined together in some circumstances. For instance, segmentation analysis could also be applied in situation 1 to offer an understanding of various landscape elements and their organizations during movements beyond the Isovist analysis only focusing on water bodies.

This study does not provide the complete process of applying the two methods to spatial design, but only shows the possibility of their design potential in a highly simplified form through three application situations. However, based on the ASE paradigm of design processes mentioned in section 1, it is evident that they could be parts of the design iterations, including analysis, synthesis (design), and evaluation (Figure 8). Here, designers could use them to analyze and understand the existing situation, test and evaluate ideas or intentions, and compare different options to make final decisions.

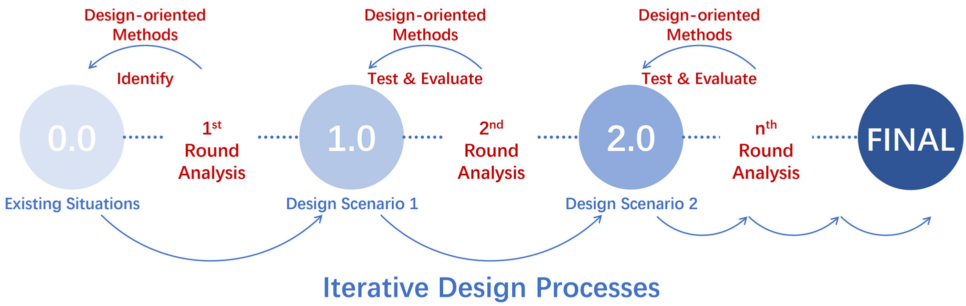

Fig. 8: The iterative design process and the role of practical design-oriented digital methods (Adapted from LIU & NIJHUIS 2020a)

Nowadays, with the advancement of technology, digital methods and tools are being widely investigated and introduced into spatial design practices, greatly expanding the toolbox of designers. The two methods presented in this study could serve as an inspiration to encourage exploration of the potential of multi-disciplinary methods to be incorporated into design processes. However, the traditional means (e. g. sketches or models) cannot be overlooked and should be combined with the digital methods to achieve design objectives better and improve the development of the knowledge/evidence-based design approach. In addition, this study has several limitations. First, this study cannot include all possible methods and only provides limited applications to inspire future research. Second, the landscape is dynamic and greatly affected by time or season, especially for water bodies and vegetation. People may have greater blue visibility in winter since the leaves are gone. Last, the data acquisition or precisions, quantity of site photos, processing power or time, etc, may influence the results. Future research can optimize these factors to improve the effectiveness and practicability of the methods.

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