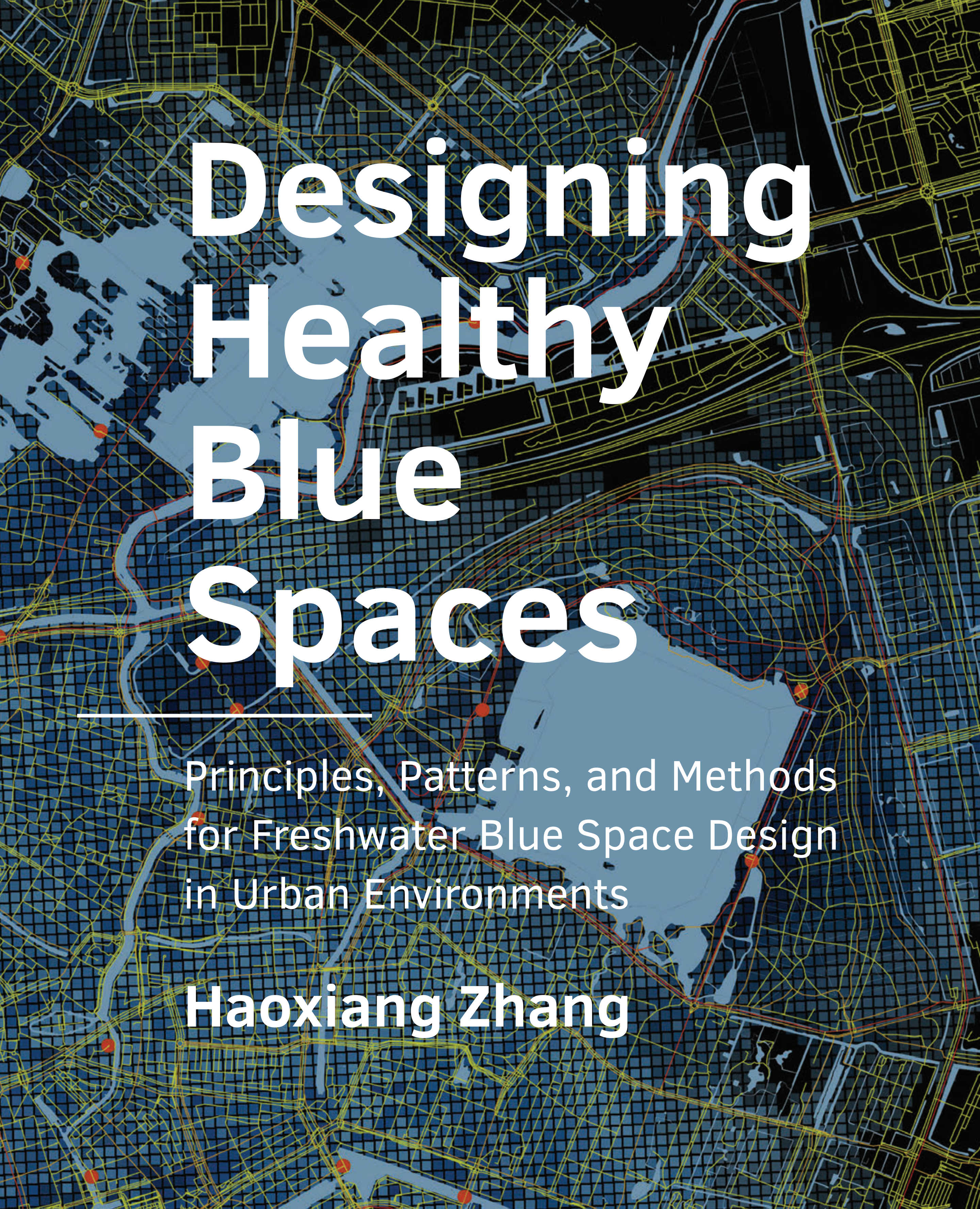


Designing Healthy Blue Spaces

Principles, Patterns, and Methods for Freshwater Blue Space Design in Urban Environments

Haoxiang Zhang

Designing Healthy Blue Spaces

Principles, Patterns, and Methods for Freshwater Blue Space Design in Urban Environments

Haoxiang Zhang

TOC

A+BE | Architecture and the Built Environment | TU Delft BK

25#06

Design | Sirene Ontwerpers, Véro Crickx

Cover photo | Haoxiang Zhang

ISBN 978-94-6384-751-3
ISSN 2212-3202

Designing Healthy Blue Spaces

Principles, Patterns, and Methods for Freshwater Blue Space Design in Urban Environments

Dissertation

for the purpose of obtaining the degree of doctor
at Delft University of Technology
by the authority of the Rector Magnificus, prof.dr.ir. T.H.J.J. van der Hagen
chair of the Board for Doctorates
to be defended publicly on
Thursday 6 March 2025 at 12:30 o'clock

by

Haoxiang ZHANG
Master of Architecture, Southeast University, China
born in Taiyuan, China

TOC

This dissertation has been approved by the promotors.

Composition of the doctoral committee:

Rector Magnificus,	chairperson
Prof.dr.ing. S. Nijhuis	Delft University of Technology, promotor
Dr. C.E.L. Newton	Delft University of Technology, promotor

Independent members:

Prof.dr.ing. S. Lenzholzer	Wageningen University & Research
Prof.dr. Y. Cheng	Southeast University, China
Prof.dr. J. Rijke	HAN University of Applied Sciences
Prof.dr.ir. M.J. van Dorst	Delft University of Technology
Prof.dr.ing. C.M. Hein	Delft University of Technology

This research was funded by the Chinese Scholarship Council (CSC) under Grant No. 202001650004 and the Dutch Organisation for Internationalisation in Education (Nuffic) under Grant No. CPI.20/00065.

Acknowledgements

Many have humorously referred to a PhD as 'permanent brain damage', hinting at the colossal effort required to complete it. However, thanks to the steadfast support and encouragement from many, my PhD journey was filled with joy and achievement. Without their invaluable contributions, my research would not have been possible. I am deeply grateful for their guidance, encouragement, and companionship during this challenging yet rewarding phase of my life.

I must express my profound gratitude to my promotors. Professor Steffen Nijhuis's wisdom and foresight not only guided my research direction but also provided great support whenever I faced challenges. After each meeting, Professor Nijhuis could precisely identify the core issues and offer insightful suggestions that were immensely beneficial to me. Beyond academics, I am also deeply grateful for the warmth and kindness he and his wife, Monique Nijhuis, extended to me. Their support in both my studies and daily life made my time here much more enriching. The wonderful experiences we shared traveling together in China and the Netherlands remain some of my most cherished memories. I am also extremely fortunate to have Dr. Caroline Newton as my co-promotor. She not only supported my ideas, giving me great freedom in my research, but also provided invaluable guidance at critical moments. I remember her generosity in sharing both her experiences and key materials with me, which played a crucial role in shaping my academic journey. Her thoughtful feedback helped me refine my research step by step, allowing me to uncover the deeper potential of my work. Additionally, I am thankful to the department's secretaries and faculty members for their invaluable support and for organising inspiring activities, especially to Gregory Bracken, Rosa de Wolf, Frank van der Hoeven, and Véro Crickx for their invaluable help in editing, formatting, and publishing the thesis. Your enthusiasm and professionalism have not only smoothed my academic path but also enriched my personal growth.

Throughout my academic journey, I have encountered a range of emotions from intense joy to periods of depression and bouts of self-doubt. I am incredibly lucky to have Xuan Meng by my side, whose outstanding support and care have been indispensable. I am also deeply grateful to my parents, Shaojia Zhang and Guiping Qi, whose constant love and encouragement have been a steady foundation for me. Their infinite patience and empathy have alleviated my struggles and brought light to my most challenging times.

I would like to extend my heartfelt gratitude to all of the scholars and designers who participated in this study, Machiel van Dorst, Yuning Cheng, Sanda Lenzholzer, Carola Hein, Jeroen Rijke, Sjerp de Vries, Anne Loes Nillesen, Mariëlle Beenackers, Michiel van Driessche, Vera Konings, Claudiu Forgaci, Shi Cheng, Mei Liu, Ziting Bao, Xiang Zhou, Yinhua Tao, Li Lu, Lu Shan, and Kaiyi Zhu. Their substantial investment of time, effort, and goodwill has been essential to the success of this research. The dedication and commitment shown by each scholar have not only made this study possible but have also enriched its outcomes significantly. Their willingness to share their insights and experiences has been invaluable, and for that, I am deeply thankful.

I am grateful for the incredible support and collaboration within our landscape architecture group, including Yuyang Peng, Shile Zhou, Yuan Chen, Monica Veras Morais, Yu Huan, Mustiafiz Al Mamun, Amna Riaz, Lei Xia, Jingsen Lian, Yifei Zhao, Pooja Boddupalli, Junkai Lan, Xinyu Zhao, Zaichen Wu, Rosa de Wolf, Yuka Yoshida, Jorrit Parmentier, Cristian Seguel Medina, and Zian Wang. Our group has been more than just colleagues; we are close friends who actively engage in rigorous academic discussions and work together to solve complex problems, significantly enhancing our collaborative efforts.

Beyond the academic setting, my journey was enriched by friends who shared in all facets of life. The culinary companions like Yu Huan, Yuyang Peng, Xiaoxia Zhang, Jun Wen, Mei Liu, Shiyu Wang, Sitong Luo, Yifei Zhao, Jiefang Ma, Shuyu Zhang, Gong Zhang, Nan Bai, Yizhao Du, Diwen Tan, Ziao Wang, and Peijun Lu, delighted me with their home-cooked meals, turning everyday dining into a feast of flavours. My travel buddies, such as Yu Huan, Yinhua Tao, Shiyu Wang, Yuan Chen, Yiran Zhang, Xiaoxia Zhang, Zaichen Wu, Yifei Zhao, Jingsen Lian, Sitong Luo, Ziting Bao, Yuanli Li, Dong Su, and Maoran Sun, with whom I explored new sights and shared exciting adventures, helped me to see the world in new ways. Friends like Yinhua Tao, Yiran Zhang, Shi Cheng, Xianbin Xie, Lu Shan, Maoran Sun, Yuanyue Zong, Chen Shen, and Yixian Zhao were there for everyday moments, providing laughter and light during demanding times. In the gym, fitness partners like Yu Huan, Shiyu Wang, Zaichen Wu, and Yimin Zhu kept me physically active and mentally sharp. Meanwhile, supportive peers such as Biyue Wang, Bo Li, Cehao Yu, Chi Jin, Cinco Yu, Daniele Cannatella, Danielle Hellendoorn, Diwen Tan, Enshan Chen, Istiaque Ahmed, Jin Huang, Langzi Chang, Liqi Cao, Neil Ibrahimli, Ran Pan, Shenglan Du, So Yeon Park, Weixiao Gao, Xu Shan, Xudong Zhang, Yanming Wu, Yan Song, Yang Liang, Yingwen Yu, Yizhao Du, Yingying Gan, Yu Li, Zhuoran Jia, and Ziao Wang provided encouragement and friendship, making my journey even more fulfilling. The collective support from these groups not only enriched my social life but also bolstered my resilience, making my PhD experience not only manageable but truly enjoyable. I am immensely thankful to all for standing by me through this significant chapter of my life.

I am profoundly fortunate to have been mentored by such caring and thoughtful educators throughout my academic journey. During my master's program, Professor Jianguo Wang provided invaluable guidance, and Professor Yuning Cheng shaped my foundational years during my bachelor's studies. Their unwavering dedication has fueled my passion for learning and continuous curiosity about the world. This study is dedicated to all the teachers who have had a transformative influence on my life. Their commitment to education has not only enriched my knowledge but has also profoundly influenced my personal and professional development.

Contents

List of Tables

List of Figures

Summary

As urbanisation reshapes routines worldwide, the prevalence of lifestyle-related chronic diseases has increased, raising public health concerns. By 2030, over 60% of the global population will live in urban areas (Rydin et al., 2012), underscoring the need for cities to support health and align with sustainable development goals (SDGs). Evidence shows that exposure to nature significantly benefits health (Bratman et al., 2019; Hartig et al., 2014; Markevych et al., 2017), positioning the natural environment as a key element in preventing non-communicable diseases. While green spaces have been widely studied, the importance of blue spaces for public health in urban settings is less recognised, though interest has grown in recent years (Bell et al., 2021; McDougall et al., 2020; White et al., 2020). Achieving the health benefits of these spaces in densely populated urban areas requires collaborative efforts from researchers and practitioners (Giles-Corti et al., 2016). Despite the growing body of evidence on the benefits of blue-green spaces, there is a vital need for practitioners to effectively apply these insights (WHO, 2021; H. Zhang et al., 2022). As landscape architects specialise in planning, designing, and managing natural environments, they are ideally positioned to play a pivotal role in translating and implementing this evidence into practice.

To advance the application of health-promoting evidence related to urban natural environments (particularly blue spaces) in spatial practice, it is essential to view the current evidence through the lens of practitioners, providing them with useful implementation tools. Landscape designers require tailored design knowledge to effectively incorporate the health benefits of natural environments into their projects. As the scientific interpretation of the design process and design research evolves, coupled with the emergence of new evidence, traditional experience-based approaches become less sufficient to the complexities of modern urban contexts. An urgent need exists for evidence-based, interdisciplinary, and multi-perspective design knowledge, particularly regarding the health benefits of natural environments. **Therefore, the main objective of this study is to establish a bridge between health-promoting evidence and the spatial design of blue spaces, offering practical tools to guide future interventions and enhancing the understanding of blue health research.** This need led to the following principal research concerns:

Understanding Blue-health Research from a Spatial Perspective

Understanding blue-health studies from a design perspective is crucial for effectively translating health evidence into practice. Employing an approach combining scientometric analysis and manual review methods, this project proposes a concise, six-step bidirectional framework to bridge evidence and practice. Subsequently, it outlines the existing knowledge on the connections among freshwater blue space, health, and design. Over the past two decades, research into blue-health has intensified, focusing on mechanisms linking freshwater blue spaces to health, their varied health benefits, and their role in addressing global challenges. Recent trends highlight research on experience and usage, psychological outcomes, and age-specific health benefits. This overview, combined with the framework, reveals a critical gap: the insufficient exploration from the design perspective, encompassing both direct guidance on spatial interventions and the evaluation of design outcomes.

A Methodological Framework for Linking the Health Benefits of Blue Space with Design Practices

A methodological framework is essential for translating health evidence into practical design knowledge and integrating it into spatial practices, facilitating the translation process and serving as a critical reference for practitioners across disciplines. Based on a comprehensive review, the research identifies four main pathways linking freshwater blue space with human health: improving ambient physical environments, enhancing physical activity, benefiting psychological outcomes, and promoting social interactions. Subsequently, a four-step framework is developed to translate health evidence into actionable design knowledge, which is then detailed through case studies. The steps include extracting key health evidence, summarising essential design concepts, categorising core design themes, and translating these into specific design principles, spatial patterns, and evaluation methods. Using the 'Analysis–Synthesis–Evaluation' (ASE) paradigm, the study further explores integrating this knowledge into the iterative design process.

Practical Knowledge for Enhancing Blue Space Accessibility, Visibility, and Quantity

Practical design knowledge provides designers with essential references for implementing the health benefits of blue spaces adaptively, tailored to different site conditions. The methodological framework identifies four key design themes – accessibility, quantity, visibility, and quality – to guide the development of practical design knowledge. Notably, enhancing accessibility, visibility, and quantity primarily focuses on the objective characteristics of blue spaces. Therefore, design principles,

spatial patterns, and evaluation methods are components of design knowledge related to these three themes. This study extracts design principles and spatial patterns from cases with global precedence, presenting them with analytical visualisations to ensure future adaptability. For evaluation methods, this study compiles eight interdisciplinary qualitative and quantitative geospatial analysis tools differentiated by scales and design themes. These design principles and spatial patterns provide intuitive references for practitioners, while the evaluation methods offer tools for assessing site conditions and evaluating the effectiveness of design knowledge applications.

Practical Knowledge for Improving the Blue Spaces Quality

The quality of blue spaces plays a crucial role in shaping public preferences and the willingness of various groups to engage in activities within these areas, thereby influencing the health benefits they derive. This study systematically analyses the relationship between blue space quality and physical activity (a proxy for health benefits) through case studies in Rotterdam, translating these findings into design knowledge for enhancing spatial quality. The analysis employs multi-source data (i.e. VGI, SVI, and POI data) and machine learning techniques, taking into account demographic variations in spatial preferences and physical activity types. The findings reveal that physical activity levels vary according to the design and type of blue space, highlighting significant differences across activities and age groups. Based on the results of the analysis, the study tailors design principles and spatial patterns to enhance the quality of blue spaces, considering the environmental preferences of varying age groups and the needs of various physical activity types. This approach provides practitioners with valuable tools and deepens the understanding of the mechanisms linking blue space with health.

Application of Practical Design Knowledge

The design principles, spatial patterns, and evaluation methods linked to the four themes equip practitioners with tools to harness the health benefits of blue spaces effectively. However, given the vast array of design possibilities, the clarity and usability of the proposed design knowledge significantly influence the outcomes of their implementation in the blue space design process. This study assesses the usability and effectiveness of the proposed design knowledge via a workshop involving 15 master’s students and PhD candidates from diverse design disciplines. Conducted on the TU Delft campus, the workshop utilises two distinct sites with different environmental characteristics for design experiments. The design knowledge, aimed at enhancing the accessibility, visibility, and quantity of blue space, serves as the primary instrument for the experiments. The design outcomes,

supplemented by field observations and post-evaluation forms, confirm the utility and user-friendliness of the design knowledge. Additionally, participants provide valuable feedback, further enhancing its practical potential.

Reflection on Applying Practical Design Knowledge in Spatial Practices

In daily practice, design knowledge is crucial as it provides direct references for spatial interventions and facilitates communication among stakeholders. However, its potential to implement the health benefits of blue spaces may be constrained by factors like practitioners' attitudes, knowledge depth, and technical proficiency, as well as the abstract nature of health as a design objective. To address this question, interviews with six experts from various spatial disciplines assess the usability and effectiveness of the proposed design knowledge and explore the feasibility of prioritising health benefits in future spatial interventions. The findings indicate that while experts recognise the practicality of the design knowledge and suggest ways for its optimisation, fully integrating health benefits into current practices is challenging. Nonetheless, they provide valuable insights for enhancing the implementation of blue space health benefits and suggest directions for future research.

In summary, this study explores the potential of blue spaces as a public health resource and seeks specific strategies to implement its health benefits through spatial interventions. A comprehensive review of current blue-health evidence from the spatial design perspective provides fresh insight into the existing research, highlighting its limitations and aiding the translation and implementation of evidence. Built on the collected evidence, a methodological framework delineates the process of converting health evidence into practical design knowledge, illustrated through direct cases. Various types of design knowledge serve dual purposes: they provide practical tool support for the real-world design processes; further, diverse approaches to generating design knowledge extend blue-health studies and the design research paradigm. A workshop validates the usability and effectiveness of proposed design knowledge through design experiments, demonstrating its integration potential in real-world scenarios. Experts from diverse fields review the practical applications of this design knowledge, assessing its potential and suggesting enhancements. They also address the challenges of incorporating health benefits into broad spatial interventions and discuss future directions. The study outcomes aim to promote the application of blue space health benefits in practices and enhance the theoretical base of blue-health research, contributing to the development of healthy cities and the achievement of sustainable development goals (SDGs).

Samenvatting

Naarmate verstedelijking wereldwijd de dagelijkse routines verandert, neemt de prevalentie van levensstijl gerelateerde chronische ziekten toe, wat leidt tot toenemende bezorgdheid over de volksgezondheid. In 2030 zal meer dan 60% van de wereldbevolking in stedelijke gebieden wonen, wat de noodzaak benadrukt om steden zo in te richten dat ze de gezondheid bevorderen en aansluiten bij de duurzame ontwikkelingsdoelen. Er is steeds meer bewijs dat blootstelling aan de natuur aanzienlijke gezondheidsvoordelen biedt, waardoor de natuurlijke omgeving een cruciale rol speelt bij de preventie van niet-overdraagbare ziekten. Hoewel groene ruimten uitgebreid zijn bestudeerd, wordt het belang van blauwe ruimten voor de volksgezondheid in stedelijke gebieden minder erkend, ondanks de groeiende interesse in de afgelopen jaren. Om de gezondheidsvoordelen van deze ruimten in dichtbevolkte stedelijke gebieden te realiseren, is samenwerking tussen onderzoekers en praktijkprofessionals essentieel. Ondanks het toenemende bewijs voor de positieve effecten van blauwgroene ruimten, is er een dringende behoefte aan praktijkgerichte expertise om deze inzichten effectief toe te passen. Landschapsarchitecten, gespecialiseerd in het plannen, ontwerpen en beheren van natuurlijke omgevingen, bevinden zich in een ideale positie om een sleutelrol te spelen bij het vertalen en implementeren van dit bewijsmateriaal in de praktijk.

Om de toepassing van gezondheid bevorderend bewijsmateriaal met betrekking tot stedelijke natuurlijke omgevingen, met name blauwe ruimten, in de ruimtelijke praktijk te bevorderen, is het essentieel om het bestaande bewijsmateriaal te bekijken door de lens van praktijkprofessionals en hen te voorzien van bruikbare implementatie-instrumenten. Landschapsontwerpers hebben ontwerpkennis op maat nodig om de gezondheidsvoordelen van natuurlijke omgevingen effectief in hun projecten te integreren. Naarmate de wetenschappelijke interpretatie van het ontwerpproces en het ontwerponderzoek zich verder ontwikkelt, in combinatie met de opkomst van nieuw bewijsmateriaal, schieten traditionele, op ervaring gebaseerde benaderingen steeds vaker tekort bij de complexiteit van moderne stedelijke contexten. Er is een dringende behoefte aan op bewijs gebaseerd, interdisciplinaire en multi-perspectief ontwerpkennis, met name met betrekking tot de gezondheidsvoordelen van natuurlijke omgevingen. **Daarom is het hoofddoel van dit onderzoek om een brug te slaan tussen gezondheid bevorderend bewijsmateriaal en het ruimtelijk ontwerp van blauwe ruimten, om praktische hulpmiddelen te bieden voor toekomstige interventies en om het begrip van onderzoek naar blauwe gezondheid te verdiepen.** Deze behoefte heeft geleid tot de volgende onderzoeksvragen:

Blauwgezondheidsonderzoek Begrijpen Vanuit Een Ruimtelijk Perspectief

Het begrijpen van blauw-gezondheidsstudies vanuit een ontwerpperspectief is essentieel voor het effectief vertalen van gezondheidsbewijsmateriaal naar de praktijk. Door een aanpak te hanteren die scientometrische analyse combineert met handmatige reviewmethoden, stelt dit project een beknopt zesstappenmodel voor om een brug te slaan tussen wetenschappelijk bewijs en ruimtelijke praktijk. Vervolgens brengt het de bestaande kennis in kaart over de relaties tussen zoetwater-blauwe ruimten, gezondheid en ontwerp. In de afgelopen twee decennia is het onderzoek naar blauwe ruimten sterk toegenomen, met een focus op de mechanismen die deze ruimten verbinden met gezondheid, hun uiteenlopende voordelen en hun rol bij het aanpakken van mondiale uitdagingen. Recente trends benadrukken onderzoek naar gebruikerservaringen, psychologische uitkomsten en leeftijdsspecifieke gezondheidsvoordelen. Dit overzicht, in combinatie met het voorgestelde raamwerk, onthult een cruciale lacune: de beperkte verkenning vanuit een ontwerpperspectief, dat zowel directe richtlijnen voor ruimtelijke interventies als de evaluatie van ontwerpresultaten omvat.

Een Methodologisch Kader voor het Koppelen van de Gezondheidsvoordelen van Blauwe Ruimte aan Ontwerppraktijken

Een methodologisch kader is essentieel voor het vertalen van gezondheidsbewijsmateriaal naar praktische ontwerpkennis en de integratie ervan in de ruimtelijke praktijk. Het vergemakkelijkt niet alleen het vertaalproces, maar dient ook als een cruciale referentie voor praktijkprofessionals uit verschillende disciplines. Op basis van een uitgebreid onderzoek identificeert deze studie vier hoofdmechanismen waarmee zoetwater-blauwe ruimten bijdragen aan de menselijke gezondheid: het verbeteren van de fysieke omgeving, het stimuleren van fysieke activiteit, het bevorderen van psychologische uitkomsten en het versterken van sociale interacties. Vervolgens wordt een vierstappenraamwerk ontwikkeld om gezondheidsbewijsmateriaal om te zetten in bruikbare ontwerpkennis, geïllustreerd aan de hand van casestudies. De stappen omvatten het extraheren van relevant gezondheidsbewijsmateriaal, het samenvatten van essentiële ontwerpconcepten, het categoriseren van kernontwerpthema’s en het vertalen hiervan in specifieke ontwerpprincipes, ruimtelijke patronen en evaluatiemethoden. Met behulp van het ‘Analyse-Synthese-Evaluatie’ paradigma onderzoekt deze studie verder hoe deze kennis kan worden geïntegreerd in het iteratieve ontwerpproces.

Praktische Kennis voor het Verbeteren van de Toegankelijkheid, Zichtbaarheid en Kwantiteit van de Blauwe Ruimte

Praktische ontwerpkennis biedt ontwerpers essentiële referenties om de gezondheidsvoordelen van blauwe ruimten adaptief te implementeren, afgestemd op uiteenlopende locatieomstandigheden. Het methodologische kader identificeert vier cruciale ontwerpthema's – toegankelijkheid, kwantiteit, zichtbaarheid en kwaliteit – die de ontwikkeling van praktische ontwerpkennis begeleiden. Met name het verbeteren van de toegankelijkheid, zichtbaarheid en kwantiteit richt zich primair op de objectieve kenmerken van blauwe ruimten. Daarom zijn ontwerpprincipes, ruimtelijke patronen en evaluatiemethoden kerncomponenten van de ontwerpkennis gerelateerd aan deze drie thema's. Deze studie extraheert ontwerpprincipes en ruimtelijke patronen uit wereldwijde casestudies en presenteert ze met analytische visualisaties om de toepasbaarheid te waarborgen. Voor de evaluatie wordt een set van acht interdisciplinaire kwalitatieve en kwantitatieve georuimtelijke analysetools samengesteld, gedifferentieerd naar schaal en ontwerpthema. De ontwerpprincipes en ruimtelijke patronen bieden intuïtieve referenties voor praktijkprofessionals terwijl de evaluatiemethoden hulpmiddelen bieden voor het beoordelen van locatieomstandigheden en het evalueren van de effectiviteit van toegepaste ontwerpkennis.

Praktische Kennis om de Kwaliteit van Blauwe Ruimtes te Verbeteren

De kwaliteit van blauwe ruimten speelt een cruciale rol bij het vormgeven van publieke voorkeuren en de bereidheid van verschillende groepen om activiteiten in deze gebieden te ondernemen, wat direct invloed heeft op de gezondheidsvoordelen die zij ervaren. Deze studie analyseert systematisch de relatie tussen de kwaliteit van blauwe ruimten en fysieke activiteit – gebruikt als proxy voor gezondheidsvoordelen – aan de hand van casestudies in Rotterdam en vertaalt deze inzichten naar ontwerpkennis ter verbetering van de ruimtelijke kwaliteit. De analyse maakt gebruik van gegevens uit meerdere bronnen (Volunteered Geographical Information, Street View Image, en Point of Interest data) en machine learning-technieken, waarbij rekening wordt gehouden met demografische variaties in ruimtelijke voorkeuren en soorten fysieke activiteit. De bevindingen tonen aan dat het niveau van fysieke activiteit varieert afhankelijk van het ontwerp en type blauwe ruimte, met significante verschillen tussen activiteiten en leeftijdsgroepen. Op basis van deze analyse worden op maat gemaakte ontwerpprincipes en ruimtelijke patronen ontwikkeld om de kwaliteit van blauwe ruimten te verbeteren, rekening houdend met de omgevingsvoorkeuren van verschillende leeftijdsgroepen en de behoeften van uiteenlopende fysieke activiteiten. Deze aanpak biedt praktijkprofessionals waardevolle hulpmiddelen en verdiept het inzicht in de mechanismen die blauwe ruimten verbinden met gezondheid.

Toepassing van Praktische Ontwerpkennis

De ontwerpprincipes, ruimtelijke patronen en evaluatiemethoden die aan de vier thema's zijn gekoppeld, bieden praktijkprofessionals concrete hulpmiddelen om de gezondheidsvoordelen van blauwe ruimten effectief te benutten. Gezien het brede scala aan ontwerpmogelijkheden zijn de duidelijkheid en bruikbaarheid van de voorgestelde ontwerpkennis echter cruciaal voor de succesvolle implementatie ervan in het ontwerpproces van blauwe ruimten. Deze studie beoordeelt de bruikbaarheid en effectiviteit van de voorgestelde ontwerpkennis via een workshop met 15 masterstudenten en promovendi uit verschillende ontwerpdisciplines. De workshop, gehouden op de campus van de TU Delft, maakte gebruik van twee locaties met uiteenlopende omgevingskenmerken als casussen voor ontwerpexperimenten. De ontwerpkennis, gericht op het verbeteren van toegankelijkheid, zichtbaarheid en kwantiteit van blauwe ruimten, diende als primair instrument voor deze experimenten. De ontwerpresultaten, aangevuld met veldobservaties en post-evaluatieformulieren, bevestigen de bruikbaarheid en gebruiksvriendelijkheid van de ontwerpkennis. Daarnaast leverden de deelnemers waardevolle feedback, wat het praktische potentieel van de ontwerpkennis verder versterkt.

Reflectie over het Toepassen van Praktische Ontwerpkennis in Ruimtelijke Praktijken

In de dagelijkse praktijk is ontwerpkennis van cruciaal belang, omdat het directe referenties biedt voor ruimtelijke interventies en de communicatie tussen belanghebbenden vergemakkelijkt. Het potentieel van deze kennis om de gezondheidsvoordelen van blauwe ruimten te implementeren kan echter worden beperkt door factoren zoals de houding, kennisniveau en technische vaardigheden van ontwerpers, evenals de abstracte aard van gezondheid als ontwerpdoelstelling. Om deze uitdaging te adresseren, zijn interviews afgenomen met zes experts uit verschillende ruimtelijke disciplines om de bruikbaarheid en effectiviteit van de voorgestelde ontwerpkennis te evalueren en de haalbaarheid van het prioriteren van gezondheidsvoordelen in toekomstige ruimtelijke interventies te onderzoeken. De bevindingen laten zien dat, hoewel de experts de bruikbaarheid van de ontwerpkennis erkennen en optimalisatiemogelijkheden aandragen, het een uitdaging blijft om gezondheidsvoordelen volledig te integreren in de huidige praktijk. Desondanks bieden hun inzichten waardevolle aanknopingspunten voor het verbeteren van de implementatie van gezondheidsbevorderende maatregelen in blauwe ruimten en suggereren ze richtingen voor toekomstig onderzoek.

Samengevat onderzoekt deze studie het potentieel van blauwe ruimten als een bron voor de volksgezondheid en richt zij zich op specifieke strategieën om de gezondheidsvoordelen ervan via ruimtelijke interventies te implementeren. Een uitgebreide review van het bestaande onderzoek naar blauwe gezondheid vanuit het perspectief van ruimtelijk ontwerp biedt nieuwe inzichten, identificeert beperkingen en ondersteunt de vertaling en toepassing van wetenschappelijk bewijs. Op basis van het verzamelde bewijsmateriaal beschrijft een methodologisch raamwerk hoe gezondheidsbevorderend bewijsmateriaal kan worden omgezet in praktische ontwerpkennis, geïllustreerd aan de hand van concrete voorbeelden. De verschillende typen ontwerpkennis dienen een dubbele functie: ze bieden enerzijds praktische hulpmiddelen ter ondersteuning van ontwerpprocessen en dragen anderzijds bij aan de uitbreiding van blauw-gezondheidsonderzoek en het ontwerponderzoekparadigma. Een workshop valideert de bruikbaarheid en effectiviteit van de voorgestelde ontwerpkennis via ontwerpexperimenten, waarbij de integratiemogelijkheden in real-world scenario's worden aangetoond. Daarnaast evalueren deskundigen uit diverse disciplines de praktische toepassing van deze ontwerpkennis, beoordelen zij het potentieel ervan en doen zij aanbevelingen ter verbetering. Ze gaan tevens in op de uitdagingen bij het integreren van gezondheidsvoordelen in bredere ruimtelijke interventies en bespreken toekomstige onderzoeksperspectieven. De onderzoeksresultaten zijn gericht op het bevorderen van de toepassing van gezondheidsbevorderende aspecten van blauwe ruimten in de praktijk en op het versterken van de theoretische basis van blauw-gezondheidsonderzoek, met als doel de ontwikkeling van gezonde steden te ondersteunen en bij te dragen aan de realisatie van de duurzame ontwikkelingsdoelen.

1 Introduction

The main objective of this research is to identify and develop practical design knowledge for freshwater blue space design to create health-supportive urban environments. This chapter introduces the problem, reveals the knowledge gaps addressed in this research, and outlines the background, relevance, and research setup.

1.1 Research Background

Water is the fundamental element sustaining all life on earth, encompassing human existence. Its significance extends beyond consumption and food production, permeating various sectors such as transportation, commerce, power generation, tourism, and recreation (Grellier et al., 2017; Solomon, 2010). Water provides almost all kinds of ecosystem services, including provisioning, regulating, cultural, and supporting services (Haase, 2015). Freshwater is increasingly significant in the urban landscape, pervading public spaces. According to Kummu et al. (2011), over 50% of the global population resides within 3 km of a surface freshwater body, particularly in Europe, Asia, and Australia, with only 10% living beyond 10 km from such locations. Therefore, freshwater intertwines with people's daily lives, encountered through commuting, recreation, and more. Due to climate change and urban renewal needs in recent decades, freshwater has become an important driver of urban transformations and landscape design to maintain water safety from rivers and oceans, solve the problem of pluvial flooding, and rejuvenate local vitality and the economy (Desfor & Jørgensen, 2004).

On the other hand, rapid urbanisation has led to reduced human interaction with nature (Frumkin et al., 2017). Research indicates that approximately half of the global population lives in urban areas, with Americans spending 90% of their time indoors (Klepeis et al., 2001; United Nations, 2018). In this context, chronic lifestyle-related diseases, such as obesity, heart disease, and type II diabetes, have become increasingly prevalent, raising significant global health concerns. Consequently, there has been an increasing scientific interest in the health and well-being benefits associated with contact or exposure to natural environments, particularly in green spaces. Simultaneously, practitioners and policymakers are widely discussing the potential of the natural environment as a practical approach to mitigating such health issues and constructing 'healthy cities', leading to a call for action to apply the health benefits of natural environments. As part of the nature-health nexus, the health benefits of contact or exposure to freshwater blue spaces have been gradually identified and recognised. To align with the 'healthy city' paradigm and attain the sustainable development goals (SDGs), it is crucial to incorporate blue spaces into future urban environments. Doing so involves actively recognising their potential as essential public health resources and incorporating their health benefits into spatial interventions.

1.1.1 Shaping City for Health

The relationship between built environments and human health is complex and interrelated. During antiquity, environmental planning was predominantly driven by fundamental survival demands, with the selection of an apt living environment contingent upon the understanding of available resources. Guided by this comprehension of human-environment interconnections, mobile communities emerged as the favoured habitation choice for early societies, where considerations of security, agriculture, and storage served as pivotal criteria for site selection. The initial link between public health and environmental planning dates back to ancient Greece, where some advocated living environments that were situated far from extreme climates to improve both human and environmental adaptability. The Romans advanced this idea by concentrating on 'fixing' the environment to better suit human habitation (Duhl & Sanchez, 1999). This approach established the overarching planning objective to establish conducive living environments, including public health requirements. Between the 13th and 18th centuries, the emergence of miasma theory (i.e. the concept that airborne vapours or 'miasma' caused most diseases) accentuated the belief that 'bad air' served as a carrier of pathogens (Davis, 2022; Tulchinsky & Varavikova, 2023). In the realm of environmental planning, this theory manifested in community organisation efforts aimed at controlling and mitigating the impact of bad air.

The genesis of modern urban planning as a distinct professional and academic discipline can be traced back to 19th-century public health initiatives, notably influenced by John Snow's groundbreaking research on the causes of cholera (Corburn, 2007). In this period, the driving ideology in public health was germ

TOC

theory, which stated that microbes were specific infectious disease agents (Susser & Susser, 1996). Public health studies focused on removing harmful elements from the environment, especially in urban areas, and several significant paradigm shifts in urban planning can be traced back to this phenomenon, including Haussmann's renovation of Paris, the Garden City concept, and the New Town movement (Duhl & Sanchez, 1999; Howard, 1965; Mumford, 1961; see Figure 1.1). Among these paradigms, urban planners focused on population concentration, the establishment of functional zoning, and the reconstruction of self-sufficient communities, aiming to improve hygiene and encourage social progress and efficiency. During this stage, urban planning and public health both relied on the germ theory and were closely related to each other (Duhl & Sanchez, 1999).

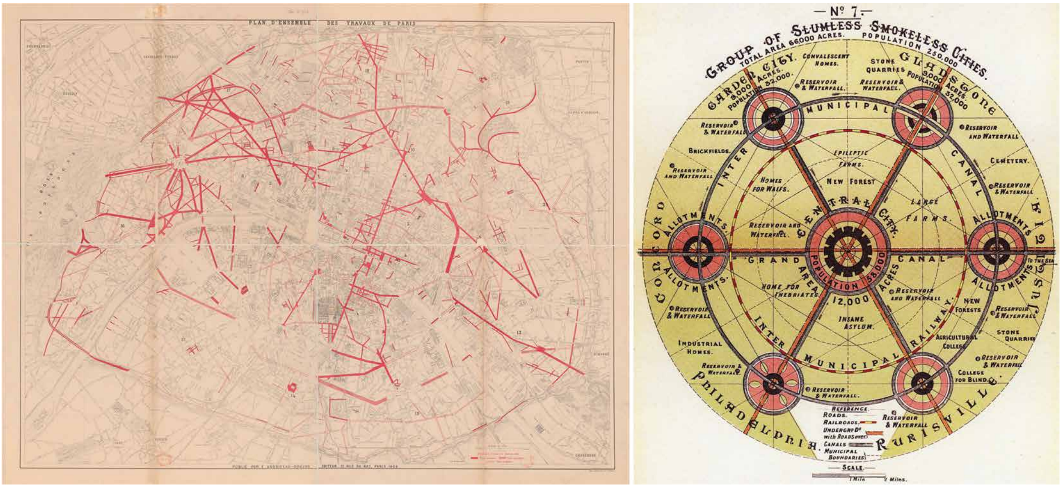


FIG. 1.1 Left: Image of Paris Around 1870 Reflecting the Typical Features of Haussmann's Renovation (Source: Paccoud, 2016); Right: Diagram of the Garden City Concept (Source: Howard, 1965).

After Word War II, the driving theory in public health shifted to the biomedical model, which recognised that not all environmental pathogens could be controlled, shifting from sanitation to immunisation. Public health officials started to seek help from physicians. Thus, the disciplinary boundaries of urban planning and public health grew, gradually separating the two disciplines (Corburn, 2007).

At present, with the epidemiologic transition to chronic, lifestyle-related diseases as the significant causes of mortality, a biopsychosocial explanation has come to compete with the previous dominant biomedical model, leading to a more holistic view of the relationship between the environment and human health (Engel, 1977).

The definition of health has evolved and is now accepted as ‘a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity’. Therefore, the relationship between the built environment and health focuses not only on the objective physical aspects of the impact but also on how people perceive, interpret, evaluate, and act in a given environment (Hartig et al., 2014). Terms such as ‘psychological stress’, ‘social support’, and ‘lifestyle-related disease’ have grown in popularity. Based on this, rapid urbanisation is regarded as one of the leading causes of current health concerns and has returned public attention to the health issues of the built environment. Over 60% of the world’s population is estimated to live in urban areas by 2030 (Rydin et al., 2012). Thus, it is essential to meet the requirements of the growing global population for healthy living in urban environments, which also relates to the sustainable development goals (UN General Assembly, 2015).

Understanding how urban environments influence health outcomes and generate health benefits is an urgent priority, as recognised by the World Health Organisation (WHO) in their declaration of 2010 as the Year of Urban Health. Recent studies have explored and identified various factors of the urban environment that could improve public health, including urban natural environments, wastewater management, building standards, and transportation systems (Rydin et al., 2012). Among them, urban natural environments have long been considered an efficient and practical means of addressing human health issues, both physically and psychologically. However, the full potential of natural environments as public health resources in urban areas has yet to be realised (Hunter et al., 2023).

1.1.2 Freshwater Blue Spaces and Human Health

Views of the health benefits of natural environments have been recorded in several ancient worlds (Ward Thompson, 2011), including Babylon, ancient Sumer, and Persia. In more recent years, the relationship between natural environments and human health has become a recurring interdisciplinary theme, gradually coming to comprise a distinct research field.

Along with extensive studies, the mechanisms linking exposure to nature, especially green spaces, to positive health outcomes have been identified, including mitigation (reducing harm), restoration (restoring capacities), and instoration (building capacities) (Hartig et al., 2014; Markevych et al., 2017; see Figure 1.2). In related research, the potential of the natural environment as a non-clinical environmental intervention for coping with non-communicable diseases has received increasing attention (Hunter et al., 2017). While natural environments have become an increasingly important aspect of public health and urban planning policies, the potential health benefits of green spaces have received far more attention than water-related blue spaces. A significant component of natural environments, blue space has been overlooked or affiliated with green space (Grellier et al., 2017). Therefore, it is necessary to focus on the relationship between human health and blue space.

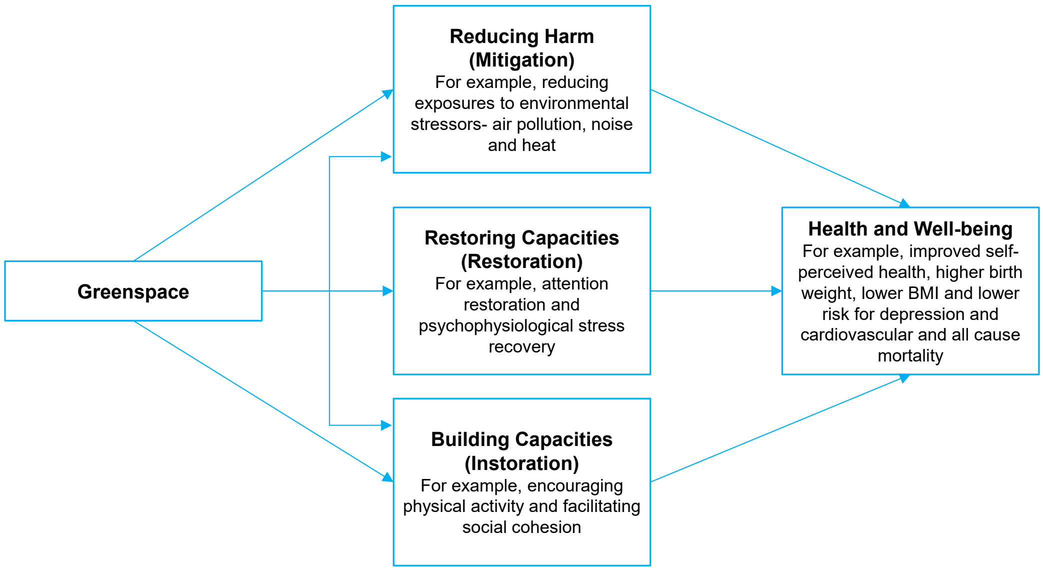


FIG. 1.2 Three Domains of Pathways Linking Green Space to Positive Health Outcomes (Source: Markevych et al., 2017).

Water and people are closely interconnected, and the term ‘blue space’ is used as a common descriptor of outdoor environments associated with water – ‘either natural or manmade – that prominently feature water and are accessible to humans either proximally (being in, on, or near water) or distally/virtually (being able to see, hear or otherwise sense water)’ (Gascon et al., 2017; Grellier et al., 2017). In general, blue space could be divided into freshwater blue space (inland blue space) and coastal environments (McDougall et al., 2020). There are considerable differences in its physical and hydrological properties, as well as people’s perception and usage of these locations. Initial investigations into the health effects of blue spaces have highlighted potential hazards to human health and well-being, including drowning, flooding, and water-borne diseases (White et al., 2020). Consequently, early academic efforts primarily conducted by environmental and public health researchers and concentrated on improving the quality of these aquatic environments and their surrounding areas to mitigate such risks. Measures have included enhancing water quality to prevent diseases and implementing safety improvements to reduce drowning incidents (Clasen et al., 2007; Meddings et al., 2021; Sinclair et al., 2009; Wade et al., 2003). As research has progressed, the role of blue spaces as crucial elements of urban public spaces has been increasingly recognised, highlighting their potential for enhancing public health. This growing interest focuses on exploring the diverse health benefits of exposure to blue spaces rather than solely concentrating on preventing potential hazards. Nonetheless, contemporary studies on coastal environments have produced relatively robust results compared to freshwater blue spaces (de Bell et al., 2017).

In recent years, the focus on waterfront revitalisation and the establishment of large-scale scientific research projects, such as the BlueHealth Programme (Grellier et al., 2017) and Blue Gym activities (Depledge & Bird, 2009), have broadened the scope of research on the health benefits of freshwater or urban blue spaces. This research, once primarily confined to environmental studies, now garners attention from multiple disciplines, including human geography, public health, urban planning, and landscape architecture (Grellier et al., 2017). Moreover, freshwater blue space is historically regarded as possessing healing qualities, including spas, baths, and other therapeutic water spaces (Foley & Kistemann, 2015). Gesler's research on these healing spaces notes that their health benefits could directly come from water (Gesler, 1992, 1998).

Recently, many studies have identified the health benefits of freshwater blue space via multiple pathways. Some researchers suggest that blue space can adopt the mechanism framework of green spaces to measure its health benefits (Garrett et al., 2019; see Figure 1.2). Based on the frameworks presented by Hartig et al. (2014) and Markevych et al. (2017), as well as other recent evidence, this study summarises four main pathways that link exposure to or contact with freshwater blue spaces and human health (The detailed description of four pathways is presented in Section 3.2): (1) enhancing physical activity, (2) benefiting psychological outcomes, (3) promoting social interaction, and (4) improving ambient physical environments (Figure 1.3). As pointed out by Hartig et al. (2014), these various pathways may occur concurrently and interact with each other when individuals come into contact with freshwater blue spaces. These pathways not only elucidate the ways in which exposure to blue spaces influences human health but also offer valuable insights for spatial planning and design.

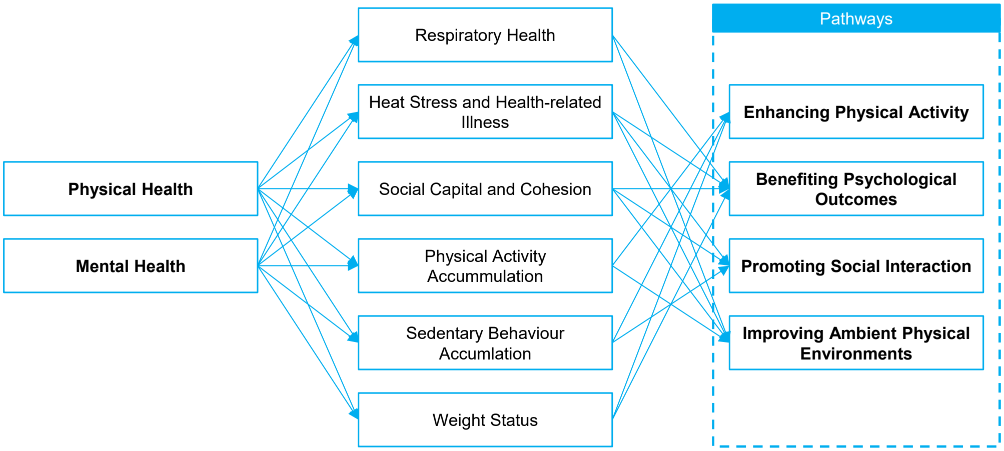


FIG. 1.3 Four Pathways Linking Freshwater Blue Space to Positive Health Outcomes.

These four pathways reveal the potential of freshwater blue space as a public health resource and non-clinical environmental intervention, the practical value of which has recently received growing attention and recognition. It is commonly acknowledged that multilevel attributes of urban environments, including green and freshwater blue spaces, could interfere with people's lifestyles, health, and well-being (Sarkar & Webster, 2017). Through effective spatial planning and urban policies, freshwater blue space can promote healthier behaviour and lifestyles and produce a higher cost-benefit ratio in health services, reducing future health costs (VanLare & Conway, 2012).

1.1.3 The Potential of Connecting Health Evidence with Design Practices

While the present study can identify and even quantify the health benefits associated with exposure to freshwater blue spaces, further studies from a spatial design perspective are warranted to offer approaches for applying these health benefits in real projects. Through such endeavours, blue spaces can be recognised as valuable public health resources and integrated into broader strategies to promote population-level health and well-being. Inspired by Rose's (1985) research in epidemiology, population-level strategies can yield more significant health impacts compared to targeted individual interventions (Figure 1.4). However, the knowledge or evidence from public health is relatively abstract and needs to become operational for landscape architects and urban designers to enable them to use this knowledge in changing spatial layouts of urban environments and creating better cities.

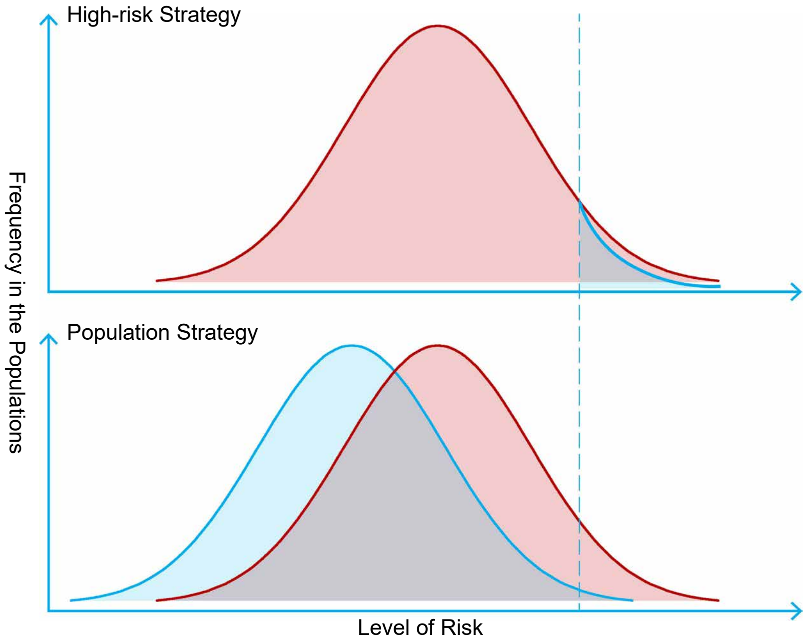


FIG. 1.4 The Effects of Population Strategy vs Individual-Level Intervention (Source: Rose, 1985).

In general, design (spatial design) can be used as a noun or a verb. Steinitz (1990) and Glanville (2014) have distinguished their different meanings. As a noun, design can be regarded as the outcome of the design process and the basis for practical implementation. As a verb, design refers to the act of projecting a future environment or object through various forms of expression. In other words, design can be viewed as an exploratory activity focusing on producing knowledge or searching for solutions to practical questions (Nijhuis & de Vries, 2019). Hence, it becomes imperative to clarify what types of knowledge and tools that can be directly employed in the design process to facilitate design development. Many studies have pointed out that the process of acquiring knowledge for design from other evidence is carried out in the context of pragmatism, which enables possible methods to develop such design-oriented practical knowledge (de Jonge, 2009). This practical knowledge serves as a direct reference and tool for design activity and generation, often conceptualised in the form of design principles, spatial patterns, and typologies, which is demonstrated in numerous studies (Nijhuis & Bobbink, 2012).

More specifically, a design principle refers to a basic idea or rule that explains or controls how something happens or works (Nijhuis & de Vries, 2019) – examples include design principles for sustainable water management, public space design, and nature-based solutions. Spatial patterns and typologies are recurring spatial arrangements that describe common situations in our environment (Nijhuis & de Vries, 2019). They can be regarded as a 'spatial language' with guiding structures or rules that explicitly shepherd decisions in a spatial way (Rowe, 1987). Well-known examples include Durand's typology in architecture, Le Corbusier's five points of new architecture, and the pattern languages proposed by Christopher Alexander. Design principles are typically abstract and broad, serving as a source of inspiration for spatial strategies, while spatial patterns and typologies are more concrete, providing specific, actionable guidance for direct interventions. What the principles, patterns, and typologies have in common is that they represent generalised design knowledge that is detached from a certain context and is applicable to other contexts (Nijhuis & Bobbink, 2012). They offer a 'toolbox' for the spatial designer, providing an overview of available spatial types or principles with essentials and leaving out particularities (Steenbergen et al., 2008). As mentioned above, the general nature of design principles and spatial patterns allows designers and planners to interpret them further when applied to actual design processes. Although the spatial pattern may provide direct and visual diagrams for illustration, it remains highly creative and flexible to users since it relays the core of the solution to various specific problems. Alexander describes the strength of the patterns as working 'in such a way that you can use this solution a million times over, without ever doing it the same way twice' (Alexander, 1977).

Hence, practical knowledge, including design principles, spatial patterns, and typologies, could provide the possibility to close the gap between public health experts and planners or designers. Spatial patterns or typologies provide designers with easy-to-understand spatial prototypes that, combined with accessible design principles, effectively inspire designers to develop their own solutions. Currently, while numerous studies conclude with recommendations for design or planning initiatives (Chen & Yuan, 2020; Garrett et al., 2019; Vert, Nieuwenhuijsen, et al., 2019; Völker et al., 2018), the majority of conclusions are broad and lack operability. As noted by Rydin et al. (2012), planners and designers should actively communicate with public health professionals and focus on practical planning processes through experimentation.

On the other hand, the knowledge/evidence-based design paradigm emphasises the imperative of deriving design principles and spatial patterns from site-specific evidence. This targeted approach significantly enhances the efficacy and impact of these principles and patterns in practical applications. To summarise, design principles, spatial patterns, and design typologies are powerful ways to transform health-related evidence into practical design knowledge. They can be useful techniques to connect public health professionals with designers or planners, as well as bring health-related evidence into the design process.

1.1.4 Applications of Design Knowledge

Although design principles and spatial patterns have shown significant potential for designers or planners to apply interdisciplinary evidence, they tend to be criticised by practitioners for underestimating the complexity of the planning and design process (Cai, 2018). Therefore, it is imperative to fully understand the design process and how to apply design knowledge. Recently, the rising prominence of design research has bolstered the use and acknowledgement of design as a valid form of research (Nijhuis & Bobbink, 2012). According to Nijhuis and de Vries (2019), research and design could be connected in four distinct ways: research for design, research on design, research through design, and research about design. Combinations of these types are often applied in real-life situations. For clarity, the term 'research through design' (RtD) is consistently used throughout this thesis, defined as 'a form of research where designing and designs are applied as a research strategy. It explores, identifies, and maps possibilities. RtD emphasises the importance of searching possibilities, which indicates the effectiveness of RtD for complex and context-specific problems, especially problems related to the built environment' (Nijhuis & de Vries, 2019). Notably, RtD is not just about the actual design but also concerns how to use design thinking to solve problems. RtD thus involves more than simply creating a design. Therefore, it is a systematic search for answers in which possible solutions are made explicit (Figure 1.5).

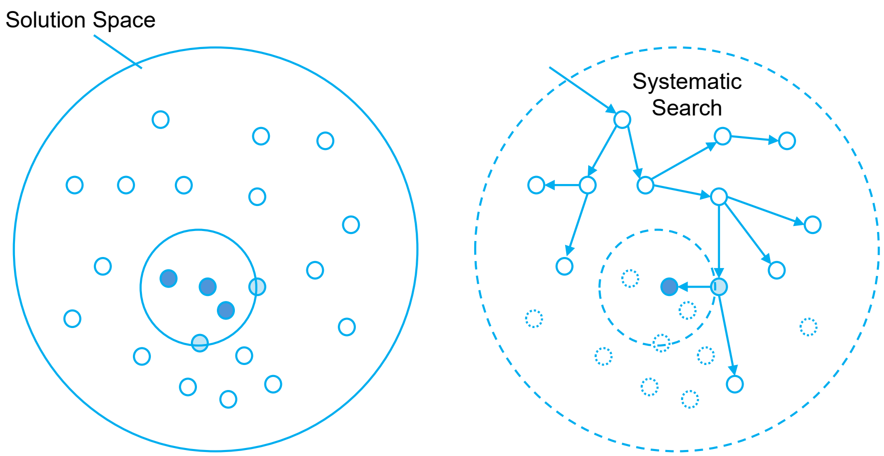


FIG. 1.5 RtD Includes a Systematic Search for the Most Effective and Efficient Solution to the Problem that Has Been Posed (Source: Nijhuis & de Vries, 2019).

Following the RtD paradigm, the design process consists of three interrelated phases (Figure 1.6): analysis, synthesis, and evaluation (Braha & Maimon, 1997; Jones, 1992; Nijhuis & de Vries, 2019). In the analysis phase, the physical structures and the socio-ecological context of the project or site will be taken into account and analysed to select what design knowledge will be applied. In the synthesis stage, designers employ creativity to devise solutions aligning with the site situations and design knowledge. As highlighted earlier, the adaptable nature of design knowledge can lead to varied design outcomes depending on the designer. Hence, the evaluation stage is crucial to assess the effectiveness of design outcomes in addressing the objectives and applications of design knowledge.

As a notable shift, alongside traditional design knowledge encompassing design principles and spatial patterns, evaluation methods have become an integral component of design knowledge. They help analyse site conditions and evaluate design outcomes, serving a dual purpose in the design process. In practice, these three stages may take place multiple times, forming an iterative process of solution generation (Figure 1.7). Consequently, RtD processes are not linear but comprise several feedback loops (Nijhuis & de Vries, 2019). To conclude, RtD offers insights into the design process, which has historically been perceived as opaque, and partly addresses critiques regarding the potential constraints of design knowledge. Nonetheless, integrating practical design testing and experimentation remains essential to optimise the practicality and validity of design knowledge, benefiting future implementations.

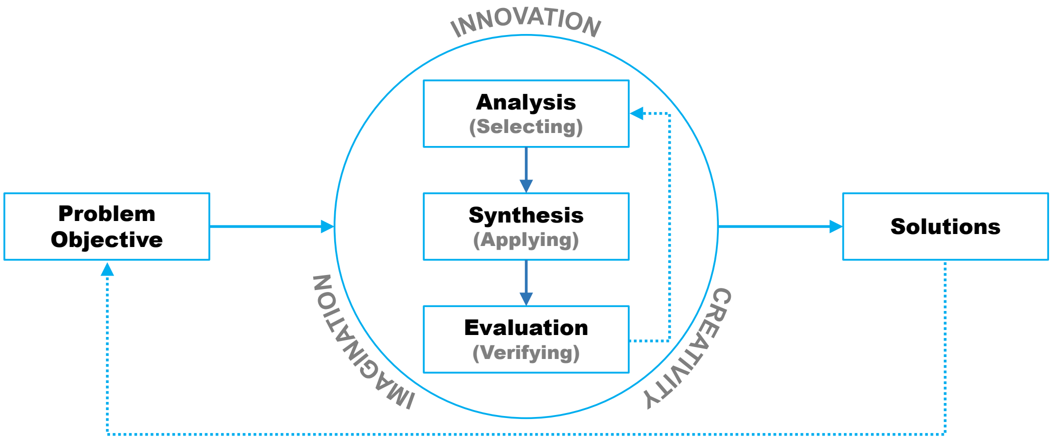


FIG. 1.6 Design Expressed as a Dialogue Between Problems and Solutions through Analysis, Synthesis, and Evaluation (Adapted from Nijhuis & de Vries, 2019).

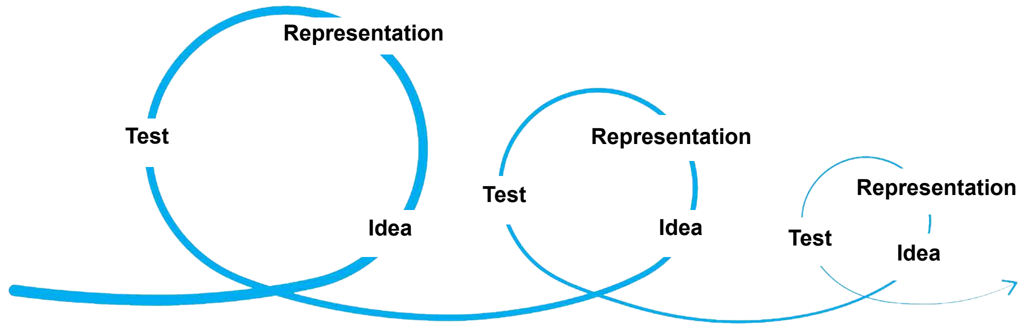


FIG. 1.7 Design Iteration Encompassing Three Phases of RtD Processes (Adapted from Nijhuis & de Vries, 2019 and Zeisel, 1984).

1.2 Problem Statement

In summary, public health has consistently been a critical factor influencing urban development. Recent studies increasingly acknowledge the natural environment's potential to mitigate chronic lifestyle-related health issues, identifying it as an essential public health resource. Although green spaces have been extensively explored both theoretically and practically, blue spaces have received comparatively less attention, especially from a practical perspective, despite the availability of relevant tools. Therefore, this research responds to a widely acknowledged problem: the insufficient consideration of public health benefits associated with freshwater blue spaces and the absence of practical and methodological support to incorporate these health benefits into design. As described in this section, the problem is three-fold: (1) the lack of a spatial and practical perspective weakens the understanding of the relationships among blue space, public health, and planning or design; (2) the scarcity of available tools further complicates the translation of accumulated health evidence into practical spatial interventions; (3) the potential limitations in interdisciplinary knowledge exchange pose challenges to the successful implementation of health evidence.

- **Insufficient Understanding of the Blue-Health-Design Nexus**
  The limited engagement of disciplines related to spatial planning and design, including urban design, landscape architecture, and urban planning, has created a gap in understanding the blue-health-design nexus from the application perspective. Currently, researchers from geography, environmental science, and public health primarily focus on collecting evidence and summarising mechanisms linking freshwater blue space and human health. While these studies have provided valuable insights, the absence of spatial design disciplines makes identifying connections between this evidence and practical implementation challenging, as highlighted by several studies (WHO, 2021; H. Zhang et al., 2022).

- **Lack of Methodological Support**
  Given the prevalence of evidence-based design and design research paradigms, the need for effective methodological support to implement the public health benefits of blue spaces has become increasingly pressing. Existing studies have pointed out that the spatial planning and design of urban natural environments could play an essential role in promoting public health and well-being (Hunter et al., 2023; Sarkar & Webster, 2017). While current health evidence could directly inform policies at the urban or population level, the over-generalisation and fragmentation of the evidence result in reduced effectiveness when applied to more nuanced and specific spatial interventions. This constraint highlights the need for practical methodological support.

- **Demands for Experimentation and Validity Studies**
  The complex and dynamic nature of urban issues in spatial design necessitates an examination and verification of the application potential of health evidence. In real spatial projects, designers must balance various factors to make comprehensive design decisions, considering the demands of multiple stakeholders and the current site situations. The public health benefits of blue spaces are just one of the potential objectives and need to be combined with on-site realities, including the physical structure and socio-ecological context, which are the key determinants of the success of a design project. Notably, implementing public health benefits requires interdisciplinary knowledge and collaboration among multiple stakeholders.

1.3 Research Objective and Research Questions

The central objective of this research is to identify and develop practical knowledge for freshwater blue space design in the creation of health-supportive urban environments. To achieve this objective, the following research questions need to be addressed:

1. **What is the relationship between freshwater blue space and human health from a spatial design perspective? (Chapters 2 and 3)**
2. **What knowledge and tools can be applied to the spatial design of blue spaces to enhance public health in urban environments? (Chapters 4, 5, and 6)**
3. **How to apply the practical design knowledge in blue space design and planning processes? (Chapters 8 and 9)**

1.4 Research Methodology

To achieve the objective and answer the research questions, a methodological framework utilising mixed methods is devised, encompassing six distinct steps (Figure 1.8). To answer research question 1, the first two steps are to conduct a comprehensive literature review on blue-health studies to understand the current research status, collect key health evidence, and summarise the mechanisms linking blue spaces and health. Based on the review results, a conceptual framework that translates the health evidence into practical design knowledge is proposed. Subsequently, steps 3 and 4 serve mainly to address research question 2 by formulating targeted practical design knowledge derived from four summarised spatial design themes extracted from health evidence. Finally, steps 5 and 6 explore research question 3, organising the design workshop and conducting expert interviews to illustrate the implementation potential of practical knowledge in design processes, thus contributing to blue-health research both theoretically and practically.

First, a comprehensive scoping review of blue-health studies is conducted to overview the status of the research field, summarise trending topics, and identify the present research vacuum. This process contributes a comprehensive view of the current state of blue-health research and serves as an initial identification of shortcomings in translating evidence into spatial interventions.

Second, a systematic review of core studies is undertaken to gather evidence on the health-promoting aspects of blue spaces and to summarise this evidence from a spatial design perspective. The findings from the systematic review inform the methodological framework to translate health-based evidence into practical design knowledge.

Next, given the objective nature of specific design themes (i.e. spatial accessibility, spatial visibility, and spatial quantity) linking health evidence and design, exemplary and pilot studies are employed to derive relevant practical design knowledge. Specifically, worldwide precedent cases serve as inspiration to generate specific design principles and spatial patterns, while pilot studies in Rotterdam demonstrate the potential application of evaluation methods. The selection criteria for these cases are based on factors such as the richness of blue spaces, project typicality, diversity, and data availability.

Fourth, recognising that spatial quality often depends on subjective experiences, two Rotterdam case studies are conducted to develop practical design knowledge aimed at enhancing the quality of blue spaces. Physical activity, specifically recreational running and cycling, are utilised as proxies for the health benefits of blue spaces. The evidence collected on the relationships between the spatial quality of blue spaces and physical activities is then translated into practical design knowledge.

Fifth, the workshop methodology is used to explore the application potential of the developed design knowledge. Fifteen participants, compassing master students and PhD candidates from TU Delft, are invited and organised into five groups to engage in a design workshop. Two testing sites within the TU Delft campus are chosen. Then, post-workshop questionnaires and interviews are conducted to evaluate the effectiveness and usability of the design knowledge and gather insights for potential improvements.

Finally, in-depth interviews with experts are organised to understand the practical potential of the design knowledge by practitioners in their daily work and discuss the future of incorporating concepts related to ‘public health’ in urban and landscape design practices.

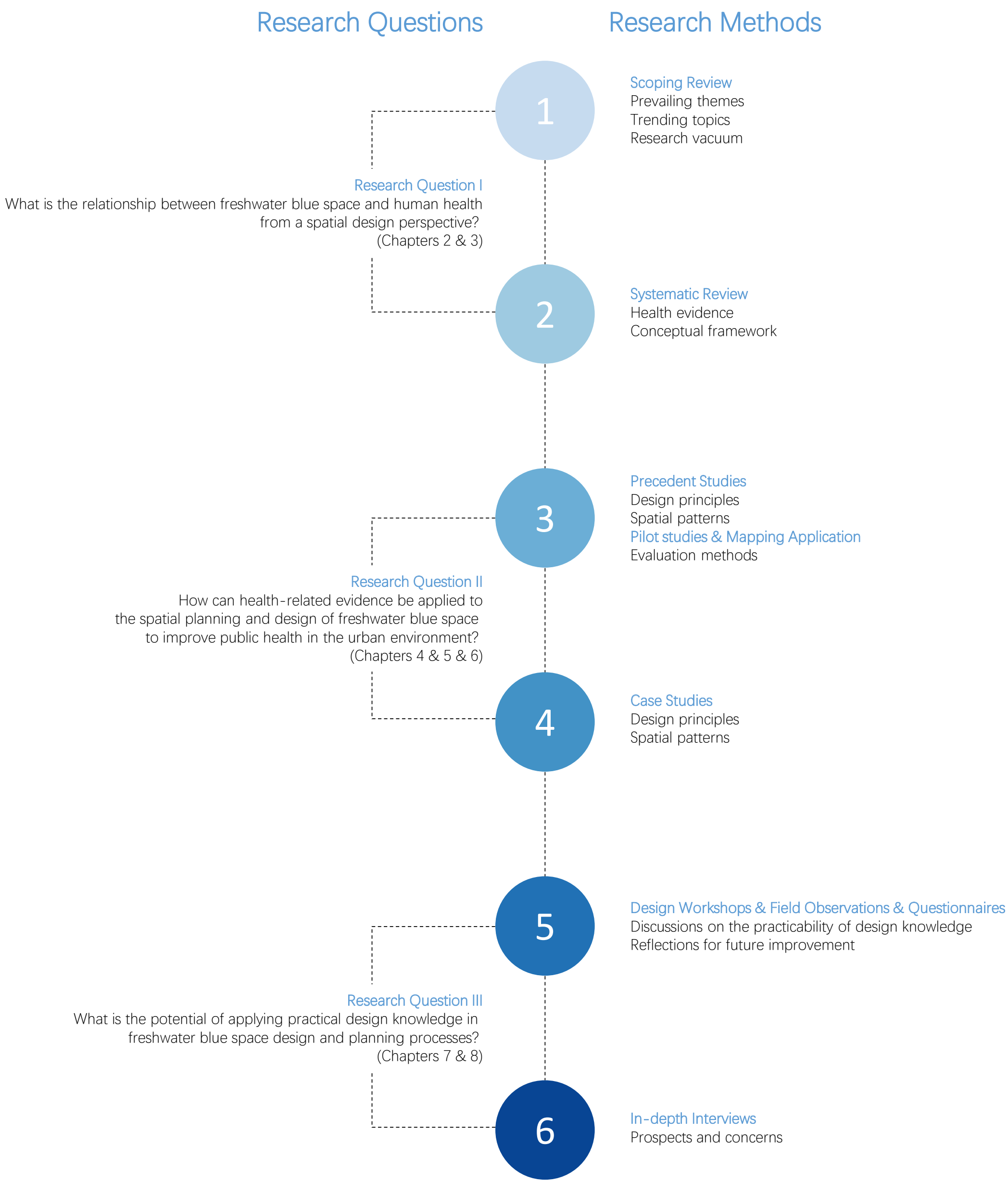


FIG. 1.8 Methodological Structure Illustrating the Research Questions and Corresponding Research Methods.

1.5 Relevance

1.5.1 Scientific Relevance

- This study provides an overview of the research concerning the interplay of blue spaces, health, and design through a scoping review, identifying prevailing themes, trending topics, and the existing research vacuum. These outcomes significantly enhance the comprehension of the existing knowledge body in blue-health research and suggest the potential for integrating current research evidence with spatial design.
- The methodological framework linking health evidence and design practice is proposed based on the available frameworks and studies. It extends the boundaries of blue-health research into practical disciplines related to spatial design, deepening the potential for interdisciplinary collaboration and inspiring other topics or future studies.
- Evaluation methods and tools pertaining to spatial accessibility, visibility, and quantity call for a multidisciplinary approach encompassing disciplines such as urban morphology, human geography, computer science, and geographical information science. These methods integrate diverse perspectives and disciplines and provide novel insights by connecting qualitative and quantitative approaches, aiding researchers in comprehending the three design themes of blue spaces.
- The empirical studies conducted in Rotterdam serve as a preliminary exploration of the connection between the quality of blue space and recreational physical activities. The integration of interdisciplinary analytical approaches and multi-source data offers methodological insights for subsequent studies. Additionally, the research outcomes form the basis for a comprehensive understanding of the association between blue space quality and healthy behaviours, speculating on the causal relationships.
- Implementing design principles and spatial patterns through the design workshop helps deepen the scientific understanding of design processes, which is traditionally viewed as a black box. On the other hand, the principles and patterns used in the workshop are the design knowledge derived from research evidence, enriching the design research or RtD approaches.

1.5.2 Societal Relevance

- The methodological framework connecting health evidence to practice serves as inspiration and reference for designers. Notably, the application of the framework can extend beyond blue spaces to other urban environments (i.e. green spaces, living environments, and workplaces), offering adaptable methodological support.
- Design principles and spatial patterns offer replicable references for real projects, aiding designers in integrating the health benefits of blue space into their daily practices. Simultaneously, they can facilitate the comprehension and communication of designers' intentions and solutions among multiple stakeholders. It is widely acknowledged that implementing public health benefits in spatial design necessitates collaborative efforts encompassing urban planners, landscape architects, policymakers, and residents.
- The design intentions and objectives should be transparent and consistent in all project processes, which enable stakeholders to evaluate the effectiveness of the spatial interventions conducted by planners and designers. Therefore, methods presented in this research can be regarded as the evaluation and communication tools for participants in design formulation, policymaking, urban management, and other processes.
- The outcomes of the design workshop effectively showcase the adaptive application of design knowledge in real-life projects, serving as a direct reference for practitioners. Expert interviews contribute to a better understanding of current challenges or concerns in integrating public health concepts into spatial interventions and developing targeted improvement strategies.

1.6 Setup of the Research

The dissertation consists of nine chapters organised into three main parts (Figure 1.9). Part I addresses research question 1 and encompasses Chapters 2 and 3. These chapters analyse the current state of blue-health research through comprehensive literature reviews and evidence collection. Next, a methodological framework is proposed to translate health evidence of blue spaces into practical design practices. Part II primarily addresses research question 2 and includes Chapters 4 to 6, which are dedicated to developing design knowledge for creating healthy blue spaces. First, design principles and spatial patterns are formulated through a global precedent analysis and case studies from Rotterdam. Subsequently, evaluation methods within the design knowledge are synthesised by integrating interdisciplinary knowledge and tools. Part III responds to research question 3 and encompasses Chapters 7 to 9. This part explores the application potential of the proposed design knowledge through design experiments and expert interviews. It also reflects on the implications of the findings and provides insights into avenues for future research. More specifically, the chapters are broken down as follows:

Chapter Two addresses the first research question by exploring the current state of blue-health research. A scoping review is conducted to provide an overview of the available body of knowledge regarding the relationships among freshwater blue space, health, and design. The findings underscore the growing attention to blue-health research and highlight the importance of variations in the utilisation and perception of blue spaces among different population groups. The state of the field demonstrates a clear and pressing need to formulate design knowledge from existing health evidence that can provide future public health benefits from blue space design.

Chapter Three further elaborates on the first research question by accumulating the health-promoting evidence of blue spaces and developing a methodological framework to translate health evidence into practical design knowledge via a systematic review. Specifically, a four-step conceptual framework related to evidence translation is proposed: (1) distilling critical health evidence, (2) summarising key design concepts, (3) categorising the core design themes (i.e. spatial accessibility, spatial visibility, spatial quantity, and spatial quality), and (4) translating themes into practical knowledge (i.e. design principles, spatial patterns, and evaluation methods).

Chapter Four begins to tackle the second research question, proposing practical design knowledge for creating health-supportive blue spaces. This chapter concentrates on introducing advanced methods to effectively analyse the objective design themes (i.e. spatial accessibility, spatial visibility, spatial quantity). Eight distinct methods are discussed, and several test cases in Rotterdam are used to demonstrate the role of these methods in evaluating the performance of blue spaces based on their quantity, accessibility, and visibility. Moreover, a flowchart for integrating these methods into cross-scale spatial design and policymaking processes is proposed and discussed.

Chapter Five elaborates on the development of the design principles and spatial patterns associated with three objective design themes (i.e. quantity, accessibility, visibility), which are the main elements of design knowledge and correspond to research question two. Precedent studies and analytical mapping/modelling are utilised to incorporate worldwide cases as inputs for deriving design principles and spatial patterns. Ultimately, these principles and patterns are categorised according to types of spatial elements and scales, offering direct references for the formation of specific spatial interventions.

Chapter Six concerns the design knowledge associated with enhancing spatial quality to harness the health benefits of blue spaces. As spatial quality is intricately tied to individuals' environmental perceptions and experiences, the proposed design knowledge is contingent on the summary of site-specific evidence. Using physical activity as a proxy for public health benefits, this chapter investigates the impact of blue space quality, with a special emphasis on eye-level quality factors and variations across different age groups, on two types of physical activities in Rotterdam. Based on the findings, several tailored design principles and spatial patterns are put forward to foster exercise-friendly and health-promoting blue spaces.

Chapter Seven approaches the third research question via a design workshop to assess the feasibility of the proposed design knowledge and to provide suggestions for further improvements. Fifteen participants, divided into five groups, joined a half-day workshop focused on designing or renovating blue spaces on the TU Delft campus to better discharge the public health benefits of blue spaces. Individual-level design principles and spatial patterns were provided to participants during the workshop. Subsequent discussions and reflections on the practicability of design knowledge were conducted through field observations of the workshop and follow-up questionnaires among participants.

Chapter Eight illustrates the results of interviews conducted with six experts from multiple disciplines (i.e. urban design, local government, landscape architecture, public health, and urban geography) to explore the potential of the proposed design knowledge that could be implemented in future practices. The interviews consist of two parts, each with a set of open-ended questions. First, leveraging their professional background and daily practice, experts deliberated on how to apply the proposed design knowledge to real design projects. Additionally, they were invited to note potential shortcomings and suggest improvements. The interviews also delve into the prospects and challenges of integrating public health concepts into spatial design, addressing experts' current concerns and envisioning future possibilities.

Chapter Nine provides a comprehensive discussion and concludes the research. It consolidates the results from each chapter, explores their relevance, acknowledges limitations in theory, data, and methods, and offers recommendations for future studies and practices in evidence collection and design knowledge development.

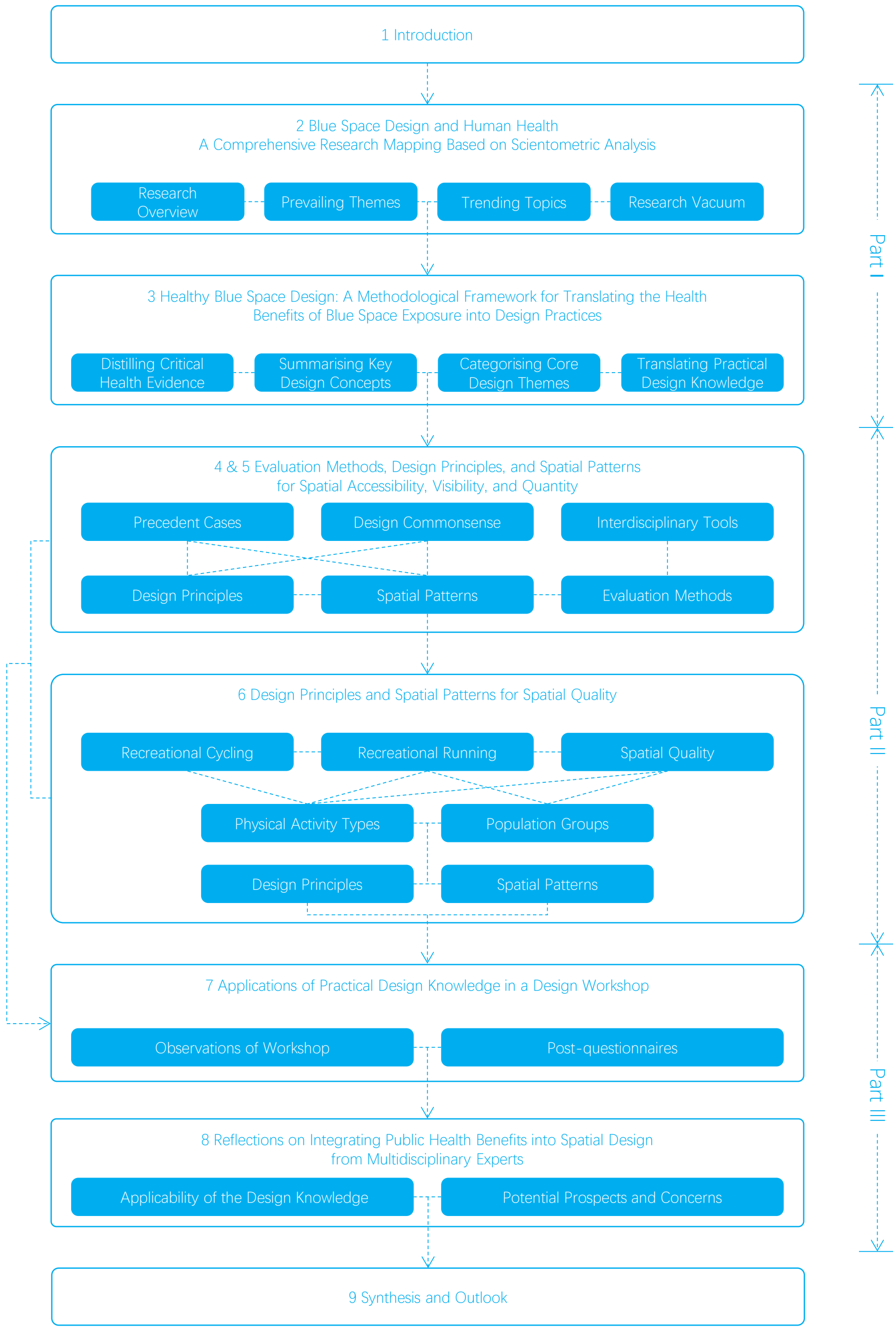


FIG. 1.9 Research Strategy Scheme and the Outline of the Dissertation.

PART I

State of the Field and Methodological Framework

With the heightened focus on public health concerns and the expanding recognition of blue spaces' potential in mitigating these issues, Part I provides a thorough overview of existing research on blue spaces and public health. It also identifies a substantial research gap, noting the disparity between health evidence and practical implementations. Building upon relevant studies and existing frameworks, a methodological framework is developed to translate health evidence into design knowledge and then apply it to spatial practices, responding to the research gap and providing methodological support for subsequent investigations. More specifically, Chapter 2 provides a comprehensive overview of existing blue-health research, and Chapter 3 delves into the construction of the methodological framework.

The contents of Chapters 2 and 3 are also published in:

Zhang, H., Nijhuis, S., & Newton, C. (2022). Freshwater blue space design and human health: A comprehensive research mapping based on scientometric analysis. Environmental Impact Assessment Review, 97, 106859. DOI: 10.1016/j.eiar.2022.106859

Zhang, H., Nijhuis, S., & Newton, C. (2024). Healthy Blue Space Design: A Methodological Framework for Translating the Health Benefits of Blue Space Perception or Exposure into Design Practices. Landscape Architecture Journal (Fengjing Yuanlin), 31 (7), 39-47. DOI: 10.3724/j.fjyl.202311130516

2 Blue Space Design and Human Health

A Comprehensive Research Mapping Based on Scientometric Analysis

This chapter provides a systematic overview of the available body of knowledge regarding the relationships among freshwater blue space, health, and design. Firstly, a brief bidirectional framework connecting health evidence with design practice is proposed. Next, scientometric analysis is employed to review 1,338 research articles on freshwater blue-health research. The results show that the number of articles in this area is increasing yearly, attracting more and more disciplines and stimulating interdisciplinary collaboration. Freshwater blue-health research has grown to emphasise usage and experience, psychological advantages, and particular demographics, which provides a solid basis for future design research. At the same time, there is clearly a significant demand to develop adaptive design knowledge that integrates the available health evidence and operationalises it in healthy blue space design.

2.1 Introduction

With the prevalence of chronic lifestyle-related diseases, people's attention to health issues is increasing globally. Rapid urbanisation has been recognised as the main factor causing these health issues (Fisher et al., 2017). Along with the expansion of the global population, it is estimated that over 60% of the world's inhabitants will live in urban areas by 2030 (Rydin et al., 2012). In this context, it is essential to meet the requirements of the growing global population for healthy living in urban environments, which are also relevant to sustainable development objectives (UN General Assembly, 2015). Therefore, understanding the urban environment from a holistic health perspective and conducting health impact assessments (HIA) are becoming increasingly important, and they provide a wide range of social, economic, and environmental benefits (Bhatia & Wernham, 2008).

The diverse health benefits of contact with natural environments have been increasingly discussed worldwide, especially in urban contexts (Hartig et al., 2014). Natural environments or nature-based interventions can be regarded as a practical approach to coping with non-communicable diseases in urban areas (WHO, 2017). While natural environments have become an increasingly important part of global public health and urban planning policies, the potential health benefits of blue spaces have received less attention than green spaces. Even compared to the distinct functions and ecosystem services of blue spaces, its health benefits have not received much attention. Over the past few years, a growing body of research has recognised this issue (Britton et al., 2020; Grellier et al., 2017; Higgins et al., 2019; McDougall et al., 2020; Smith et al., 2021; White et al., 2020). While the total number of studies remains limited, they provide more and more evidence that exposure to blue space could promote human health and well-being in multiple ways (Gascon et al., 2017; Grellier et al., 2017; McDougall et al., 2020; Völker & Kistemann, 2011; White et al., 2020).

Although the interaction between water and human health has been discussed for decades, water has generally been affiliated with green space and has not received enough attention on its own (Grellier et al., 2017; Solomon, 2010). In recent years, with the establishment of several large projects, including the BlueHealth Programme (Grellier et al., 2017), the Marine and Coastal Access Act 2009 (UK Government, 2009), and Blue Gym activities (Depledge & Bird, 2009), the relationship between water and health has reclaimed researchers' attention from multiple disciplines, including human geography, public health, urban design, and landscape architecture (Grellier et al., 2017). During the early stages of health and water research, several terms were used to describe outdoor water environments, including blue infrastructure (Haase, 2015), aquatic environment (Jones et al., 2004), and surface waters (Völker & Kistemann, 2011). These terms mainly originate from disciplines not closely related to recent health and water research. For instance, the term blue infrastructure is a broad concept that includes water supply systems with less connection to health and water research. As McDougall et al. (2020) point out, this genre has shifted from a by-product of therapeutic landscape and environmental health toward an established academic research field. Alongside the rapid development of health and water research, the term 'blue space' has emerged and has been used as a common definition for outdoor environments associated with water (Gascon et al., 2017).

In general, blue spaces can be divided into freshwater blue spaces and coastal environments (McDougall et al., 2020). There are considerable differences in physical and hydrological properties, as well as people's perceptions and usage of these spaces. Existing research on the health benefits of the coastal environment has yielded relatively robust outcomes compared to freshwater blue space, partially due to the fact that coastal environments cover a much larger area across the globe (de Bell et al., 2017). The positive effects of exposure to coastal environments on general health (Garrett et al., 2019; Gascon et al., 2017) and mental health (Dempsey et al., 2018; White et al., 2021) have been identified, while similar studies on freshwater blue space are fewer in number. Additionally, since the 1980s, waterfront rejuvenation has become a growing trend aimed at increasing access to primarily freshwater blue space. Therefore, the health benefits of freshwater blue space, an important spatial component of urban environments, deserve attention (Desfor & Jørgensen, 2004; Völker & Kistemann, 2011). While it is possible to combine freshwater and coastal blue space to some extent, it is challenging to summarise conclusions specifically connected to freshwater blue space (McDougall et al., 2020). Moreover, the transferability of these broader conclusions requires careful consideration, particularly when applied directly to the decision-making and design processes.

In response to the identified health benefits, the provision of natural environments has been regarded as an effective approach for creating a healthy urban environment in several policy documents (UN General Assembly, 2015; WHO, 2012, 2013). As a critical component of urban nature environments, freshwater blue space is attracting increasing attention (WHO, 2021). However, this attention mainly focuses on the provision of freshwater blue space rather than on its quality. Spatial design is one of the most direct approaches to improving the quality of urban environments, including freshwater blue spaces. It serves as a core activity in landscape architecture and its related disciplines, aiming to provide solutions for urban and rural areas as well as projects such as parks, gardens, and squares, creating conditions for spatial, ecological and social development (Nijhuis & de Vries, 2019). Such studies can also provide designers with detailed guidance on the spatial attributes needed to tackle lifestyle-related diseases (Douglas et al., 2017). Therefore, it is necessary to situate spatial design in freshwater blue-health research to generate a higher cost-benefit ratio in health services and reduce future health costs through this non-clinical environmental intervention (VanLare & Conway, 2012). As Rydin et al. (2012) note, design professionals should actively communicate with people responsible for public health and focus on practical design processes through project experimentation rather than linear or cyclical schemes to promote a health-oriented urban environment. For clarity, the term 'design' is consistently used throughout this chapter in reference to spatial design.

Currently, only a limited number of publications mention and review the relevant evidence from freshwater blue-health research (McDougall et al., 2020; Vári et al., 2022). Specifically, Vári et al. (2022) take a broader view and explore the relationship between ecosystem services and freshwater systems. Similar to the current research, McDougall et al. (2020) adopt a narrative method to discuss some critical issues in freshwater blue-health research, with a particular focus on the measurement of freshwater blue space exposure. However, their research has paid little attention to incorporating health benefits into freshwater blue spaces from the action side, and spatial design has not received much attention as a practical approach. Therefore, a comprehensive overview of the current status of freshwater blue-health research and its relationship to design could not only provide practical support for the establishment of healthy freshwater blue spaces and even healthy cities more broadly but also provide the methodological basis for the development of HIA and comprehensive EIA of freshwater blue spaces.

This chapter addresses the above issues by developing the conceptual framework, locating and analysing a large number of publications on freshwater blue-health research, and reflecting on the outcomes from a design perspective. **In reference to research question 1, the objectives of this chapter are to (1) propose a conceptual framework connecting freshwater blue space design and human health based on existing models, (2) conduct a scientometric analysis of the state-of-the-art knowledge on freshwater blue-health research with a particular emphasis on the role of design, and (3) summarise the trending topics and vacuum within current research by incorporating the conceptual framework and scientometric analysis.**

Specifically, this chapter is organised into the following sections. In Section 2.2, a conceptual framework linking freshwater blue space design and human health is presented. Section 2.3 introduces the data extraction and methodology of scientometric analysis used in this study. Section 2.4 gives a brief overview of current

TOC

freshwater blue-health research and identifies the prevailing themes found within this body of work. In Section 2.5, several trending topics are recognised and discussed according to an in-depth exploration of the scientometric analysis. The main gap in current research is pointed out based on the framework and results in Section 2.6. At the end of the chapter, the conclusions are organised, and future steps are suggested.

2.2 Linking Freshwater Blue Space Design and Human Health

To assist in organising the available evidence, locating the positions of several key themes, and identifying the current research gap, a conceptual framework linking freshwater blue space design and human health is proposed. This framework is based on several previous models (Figure 2.1). First, based on Markevych et al.'s (2017) and Hartig et al.'s (2014) frameworks, this research extends the main pathways linking green/blue space and health to include freshwater blue space and health (the detailed description of four pathways is presented in Section 3.2), including a) improving ambient physical environments, b) enhancing physical activity, c) benefiting psychological outcomes, and d) promoting social interaction. Second, since these four pathways are all derived from exposure and contact with freshwater blue space, following White et al.'s (2020) model, the existing evidence on exposure or contact with freshwater blue space will be collected and summarised by reviewing current research (e.g. living closer to freshwater blue space may lead to more regular contact). Next, this evidence can be translated into design concepts for implementation in freshwater blue space design (e.g. living closer to freshwater blue space can be translated into the design concept of 'residential accessibility'). Finally, according to the design research model proposed by Nijhuis & de Vries (2019), these health-related design concepts could be transformed into practical and reproducible design knowledge that can then be adapted and applied in future freshwater blue space design projects.

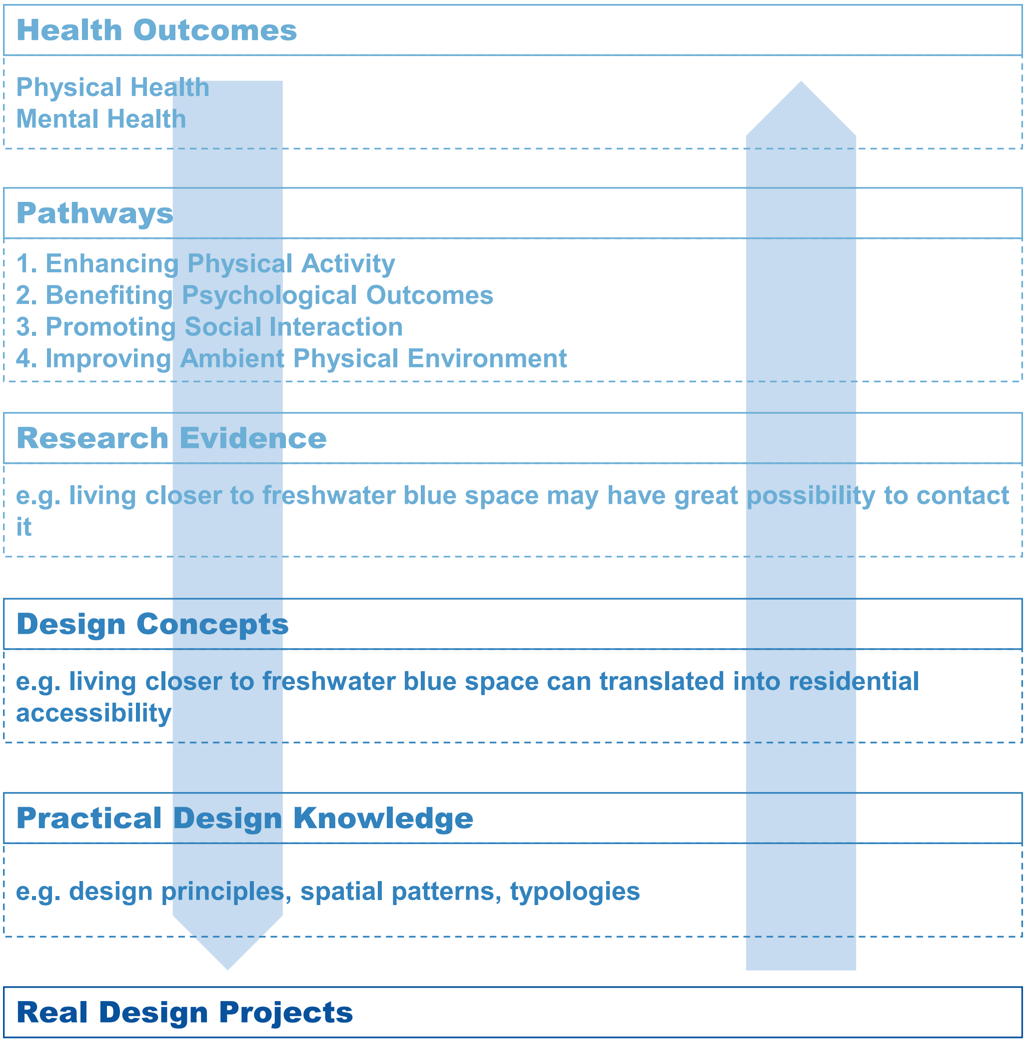


FIG. 2.1 A Framework Linking Freshwater Blue Space Design and Human Health.

Action-oriented connections between freshwater blue space design and human health are established through this six-step framework. In addition to extending and introducing several previous frameworks to freshwater blue-health research, this new framework makes four additional contributions. First, inspired by Andersson et al.'s (2019) work, the framework can be regarded as a two-way dynamic process rather than one-directional. As mentioned above, the interpretation of the framework begins with health evidence and ends with practical design knowledge and applications. On the other hand, this framework can be interpreted from below, meaning that rich project practices could provide input to refine newly introduced health evidence. Second, the framework offers preliminary methodological support for integrating health evidence into the freshwater blue space design process. Previous studies mainly focus on the health side by providing more evidence to illustrate four main pathways rather than the design or action side. Third, the evaluative nature of the framework can provide the basis for constituting HIA and EIA. The design concepts drawn from relevant studies could be regarded as indicators to assess the health effects of freshwater blue spaces. Moreover, design knowledge can be used to assist in integrating HIA and EIA into the design process, which has attracted growing attention (Fischer et al., 2021). Finally, the framework can be used to guide not only the transformation and application of health evidence in freshwater blue space design but also to inspire additional studies that actively apply health evidence in the design of other natural environments to shape healthy cities (Shanahan et al., 2015).

2.3 Methods and Materials

2.3.1 Scientometric Analysis of Freshwater Blue-health Research

Scientometrics quantitatively analyses all features of the scientific literature, and it is generally used to identify knowledge structure, scientific contributions, research developments, and emerging trends in the research domain (Rawat & Sood, 2021). In scientometrics, knowledge mapping is the primary technique to facilitate knowledge access and visualise the state of the field (Shiffrin & Börner, 2004). However, as an emerging research field, no study of freshwater blue-health field has comprehensively analysed its conceptual underpinnings by using knowledge mapping. As a result, this study relies heavily on scientometric analysis to gain a better understanding of the current situation and to discuss its relevance with design. Figure 2.2 describes the methodological process using several scientometric analysis tools.

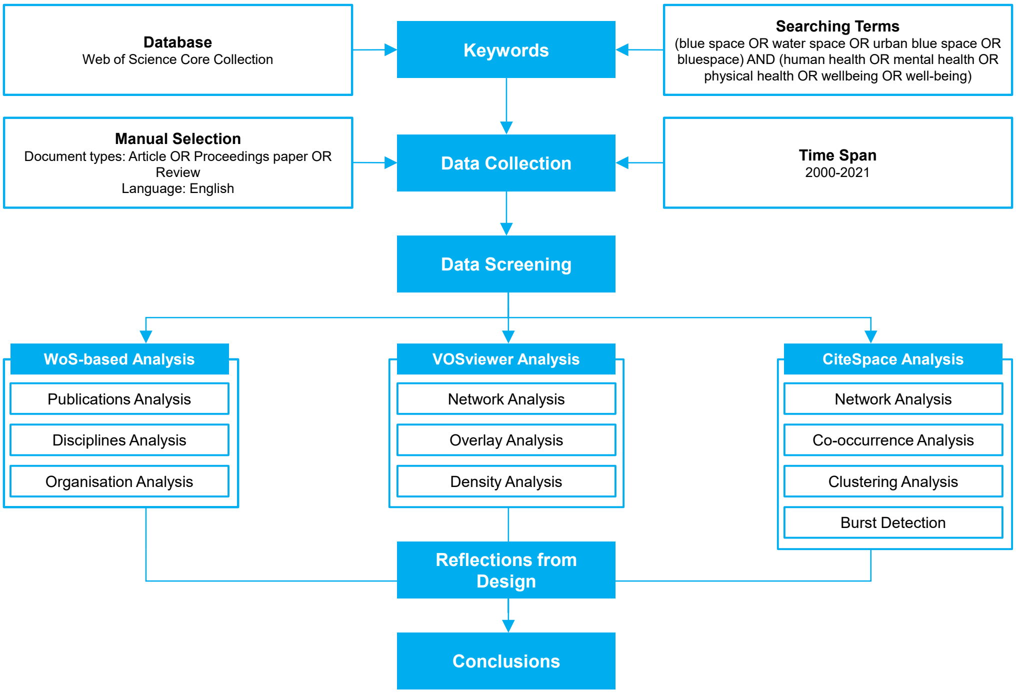


FIG. 2.2 The Flow Diagram for Scientometric Analysis.

2.3.2 Data Collection

Web of Science (WoS) is a platform that provides access to several databases containing complete citation data for various disciplines, including natural sciences, social sciences, the arts, and the humanities. Web of Science Core Collection (WoSCC) is a carefully selected WoS database that provides high-quality, credible information and is a valuable source for scientometric analyses (Azam et al., 2021). The Science Citation Index Expanded (SCI-E), Social Sciences Citation Index (SSCI), Arts & Humanities Citation Index (A&HCI), Conference Proceedings Citation Index-Science (CPCI-S), Conference Proceedings Citation Index-Social Science & Humanities (CPCI-SSH), and Emerging Sources Citation Index (ESCI) databases are selected as data sources for this research. Data was extracted on 24 April 2021 from the online library of Delft University of Technology (TU Delft), the Netherlands. The search terms were TS= (blue space* OR water space* OR urban blue space* OR bluespace* OR freshwater blue space*) and TS= (human health OR mental health OR physical health OR well-being OR well-being), and the time span was set from 2000 to 2021. The articles, reviews, and proceedings published in English were then selected. Finally, 1,338 documents were retrieved in plain text with a complete record, including cited references for further analysis.

2.3.3 Analysis Methods

2.3.3.1 VOSviewer and CiteSpace Analysis

VOSviewer and CiteSpace, leading software programs, were used to conduct scientometric analysis. VOSviewer and CiteSpace are both Java-based software programs used to create coloured maps from bibliographic data and visualise and extract the intrinsic meaning of the maps. This study performed three kinds of keywords-based visualisations from the VOSviewer to gain a direct understanding of the research field, including network visualisation, overlay visualisation, and density visualisation (Waltman et al., 2010). Each map emphasises and conveys different information. Specifically, network maps represent the primary research clusters among current bibliometric data, while density maps provide a quick overview of significant areas in the scientometric network. In addition, the overlay maps can be used to show the research development over time.

The novelty of CiteSpace lies in the deep mining of the co-citation and co-occurrence data of specific documents. Co-citation analysis (co-cited reference clusters) and co-occurrence analysis (co-occurring keywords networks and clusters) can reveal the critical keywords in papers, as well as the trending topics and concepts of the whole research field (Zhang et al., 2020). Moreover, keywords-based burst detection analysis can identify research frontiers among current publications.

Based on the advanced functions and extensive applications of VOSviewer and CiteSpace, a visualised analysis of freshwater blue-health research was carried out. The obtained data was visualised in VOSviewer (1.6.16) and CiteSpace (5.7.R4) using the following procedures, respectively. First, 1,338 documents with complete records and cited references obtained by data collection were used as input. Second, the required parameters in each software program were adjusted, and the analysis was conducted. The detailed parameters of each program are shown in Table 2.1 and Table 2.2.

TABLE 2.1 Parameters of CiteSpace.

No.	Parameters	Definition
1	Time slicing	Year span from 2000 January to 2021 December, per slice for one year
2	Term source	Title, abstract, author, keywords
3	Node type	Author, institution, country, keyword, reference
4	Links	Default
4	Selection criteria	Top 10%
5	Pruning	Pathfinder and pruning sliced networks
6	Visualisation	Cluster view-static and show merged network

TABLE 2.2 Parameter of VOSviewer.

No.	Parameters	Definition
1	Extraction fields	Title, abstract
2	Counting method	Full counting
3	Minimum occurrences	10
4	Selected terms	725

2.3.3.2 Web of Science-based Investigation

The WoS platform not only provides access to multiple databases for acquiring citation data but also contains helpful tools to analyse the search results, including the exploration of publication numbers, organisations, and research fields. These tools allow researchers to quickly and preliminarily review the search results in various diagrams or charts.

2.4 Preliminary Explorations of Scientometric Analysis

2.4.1 Overview of Freshwater Blue-health Research

2.4.1.1 Number of Articles Published

Figure 2.3 shows the number of documents in freshwater blue-health research between 2000 and 2021 in the WoSCC database. At the initial stage, this area did not receive much attention among scholars, and only a few documents were published between 2000 and 2004. However, the research field increasingly attracted attention after 2005, and the number of publications gradually increased. Although there were fluctuations in 2008, 2011, and 2014, the number of documents increased rapidly from 19 to 250 from 2008 to 2020, with an annual growth rate of 23.96%.

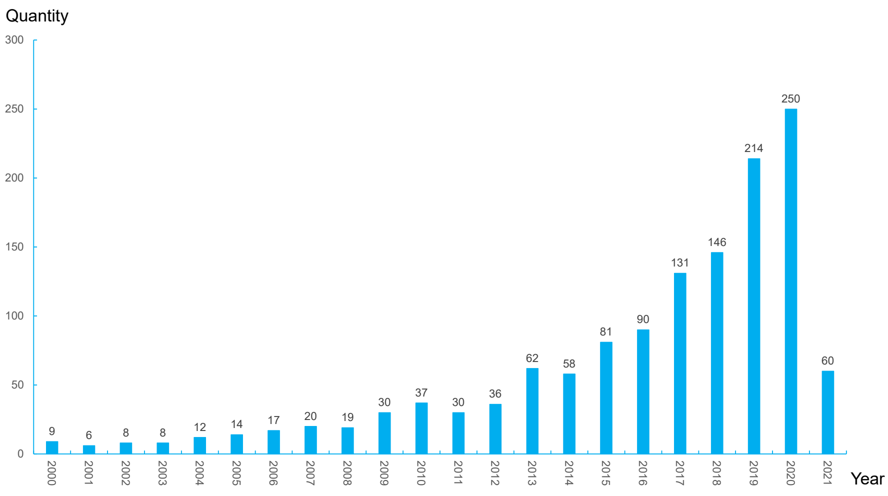


FIG. 2.3 Annual Distribution of the Studies.

2.4.1.2 Distribution of Research Disciplines

Freshwater blue-health research is a multifaceted issue encompassing several disciplines. Table 2.3 lists the top 10 fields covered by the research with the most papers in the WoSCC database. Among 1,338 documents, 425 came from environmental science, 212 from public environmental occupational health, and 175 from environmental studies, accounting for 31.76%, 15.85%, and 13.08%, respectively. In addition, water resources, urban studies, ecology, and geography play important roles in understanding the relationship between freshwater blue space and health.

TABLE 2.3 Discipline distribution of documents (Top 10).

No.	Fields	Quantity	Proportion
1	Environmental sciences	425	31.76
2	Occupational health	212	15.85
3	Environmental studies	175	13.08
4	Water resources	101	7.55
5	Urban studies	96	7.18
6	Ecology	85	6.35
7	Geography	80	5.98
8	Environmental engineering	78	5.83
9	Sustainable (green) science technology	67	5.01
10	Geosciences – multidisciplinary	58	4.34

Environmental science and environmental studies account for a large proportion of freshwater blue-health research, reflecting the importance of both natural and social sciences in this research area. In addition, according to the analysis of authors and organisations, there have been a number of publications in recent years funded by the BlueHealth project, which promotes interdisciplinary collaboration (Grellier et al., 2017). The establishment of this multidisciplinary research project indicates the growing interest of policymakers in better understanding the relationship between blue space and health and then applying this knowledge to policies and design processes. Although environmental sciences, urban studies, and geography contain some studies from design or policymaking, this is not always the case. Furthermore, most of the studies are conducted in Western developed countries. Therefore, obtaining more evidence from developing countries, especially countries in Asia and Africa with a higher pace of urbanisation, is necessary.

2.4.2 Prevailing Themes in Freshwater Blue-health Research

2.4.2.1 Main Research Keywords

Keywords are used to indicate the core contents of the research paper. Consequently, keyword analysis can provide an overview of the main topics related to freshwater blue-health research. Table 2.4 lists the top 15 occurring keywords associated with this research field. These keywords can be categorised into three main themes, including mechanisms linking freshwater blue space and human health (e.g. physical activity, ecosystem service), different health benefits of freshwater blue space exposure/contact (e.g. mental health, impact, benefit, human health), and the relationship with other global challenges (e.g. climate change, biodiversity).

TABLE 2.4 Top 15 Critical Keywords Ranked by Frequency.

Ranking	Keywords	Frequency	Year	Centrality
1	Water	273	2001	0.12
2	Green space	199	2011	0.03
3	Health	193	2002	0.10
4	Physical activity	170	2008	0.06
5	Environment	118	2009	0.02
6	Mental health	116	2001	0.03
7	City	104	2010	0.04
8	Exposure	103	2010	0.09
9	Impact	95	2008	0.02
10	Ecosystem service	86	2013	0.01
11	Space	80	2007	0.06
12	Benefit	76	2009	0.09
13	Climate change	67	2010	0.05
14	Human health	64	2013	0.00
15	Biodiversity	54	2007	0.07

Mechanisms linking the natural environment and human health have attracted considerable attention among research communities worldwide. The studies regarding green space have concluded that there are three main health-promoting pathways, including reducing harm (mitigation), restoring capacities (restoration), and building capacities (instoration) (Markevych et al., 2017). As mentioned in Sections 2.2 and 3.2, there are four main pathways linking freshwater blue space

TOC

and health based on the existing research outcomes, including improving ambient physical environments, enhancing physical activity, benefiting psychological outcomes, and promoting social interaction. Although the main pathways are widely recognised, more evidence is needed to show their applicability in different contexts.

From the framework in Section 2.2, health outcomes of freshwater blue space exposure can be seen as the higher step or outcomes of mechanisms that link exposure and health, a topic widely discussed in epidemiology and public health. True experiments, natural experiments, and observational studies have been used to examine and broaden the physical and mental health outcomes of freshwater blue space exposure (Frumkin et al., 2017).

Freshwater blue space can provide various ecosystem services and help people cope with many global challenges (Haase, 2015). A number of studies attempt to integrate the health benefits of freshwater blue spaces with other ecosystem services to comprehensively address global concerns, including health issues, biodiversity loss, and climate change (Vári et al., 2022). However, it is worth noting that existing studies have identified the complex interactions among different ecosystem services, including synergies and trade-offs (Haase et al., 2012; Hossu et al., 2019; Qiao et al., 2019). Therefore, future freshwater blue-health research could uncover such interactions between health benefits and other ecosystem services and consider them when implementing projects to make more efficient use of freshwater blue space.

While some keywords strongly connect to space, only a few are directly tied to design. There are three possible reasons for this phenomenon. First, not all research results relating to design are included in the WoSCC database; instead, they are shared via professional design magazines and reports. Second, most current research is devoted to explaining the relationship between freshwater blue space and human health, attempting to establish causal relationships (Gascon et al., 2015). As a result, it will take time to turn this evidence into practical design knowledge. Third, freshwater blue space and health research necessitate cross-disciplinary collaboration (Rydin et al., 2012). The absence of designers in the debate exacerbates the scarcity of findings immediately applicable to design.

2.4.2.2 Research Frontiers

Burst detection from CiteSpace can perceive research communities' attention to specific keywords and publications during different periods. The frequency of the keywords and the number of citations are first-level indicators representing the research themes. In contrast, keyword burst is a high-level indicator accompanying research attention in a specific period. Therefore, keywords with higher citation bursts can provide critical signals to identify research frontiers.

Table 2.5 shows 12 keywords with higher citation bursts, along with the strength and duration of the bursts from 2000 to 2021 in red. Risk assessment is the first with the most robust citation burst of 4.55, which continued for six years from 2009 to 2015. Urbanisation, long-term exposure, and greenspace are the three keywords with higher burst intensity in the past three years, presenting emerging trends and leading frontiers affecting the development of freshwater blue-health research. Urbanisation and long-term exposure have the predominant citation bursts of 4.54 and 4.16, respectively.

TABLE 2.5 Top 12 Keywords with the Most Robust Citation Burst.

No	Keywords	Strength	Begin	End	2000–2021
1	Climate	3.6	2007	2013	
2	Risk assessment	4.55	2009	2015	
3	Model	3.56	2009	2013	
4	Environment	3.33	2009	2011	
5	United States	3.62	2010	2017	
6	Neighbourhood	3.36	2014	2017	
7	Restoration	3.89	2015	2019	
8	Community	3.66	2015	2016	
9	Greenness	3.31	2018	2019	
10	Urbanisation	4.54	2019	2021	
11	Long-term exposure	4.16	2019	2021	
12	Green space	3.4	2019	2021	

Urbanisation. Urbanisation is becoming an inevitable trend worldwide. About half of the world's population lives in cities, and it is expected that by 2030, three out of every five people will live in urban areas (Lahariya, 2008). Although living in cities has many advantages, including facilitating social networks and providing many public services, it brings a series of problems that could harm human health, including air and water pollution, noise, and stress (Samet et al., 2000). In recent years, with the deepening of the field and public attention on health issues, research focusing on the health benefits of blue space has gradually shifted from natural environments (e.g. coastal environment) to the urban context. A significant volume of evidence has emerged to demonstrate that proximity to urban blue spaces could benefit human health in a similar way to green space benefits (Burkart et al., 2016; Gascon et al., 2017).

Long-term exposure. Long-term exposure is the necessary supplement for research on short-term effects. The relationship between long-term exposure and health could be essential for policymakers and designers to take appropriate policy actions or design decisions (Gascon et al., 2015). In many cases, the health benefits of blue space exposure/contact are associated with specific recreational activities (Barton & Pretty, 2010). For instance, improving mental health and social contact are frequently attributed to short-term exposure to blue space. Although the short-term and experimental research could provide evidence for the mechanisms linking blue space and health, they cannot infer causality (Gascon et al., 2015). With increasing studies regarding freshwater blue space as an essential solution for health issues caused by urbanisation (Hartig et al., 2014), it is necessary to examine the health benefits of long-term exposure to freshwater blue space (Chen & Yuan, 2020; Gascon et al., 2018). However, most studies concerning long-term exposure adopt the cross-sectional design, and few use longitudinal data (Gascon et al., 2017). For example, some studies examine the association between inhabitants' health conditions and the volume and accessibility of blue space (McDougall et al., 2020), assuming that individuals have resided in the study area for an extended period. Gascon et al. (2017) have identified the limitation of ignorance of residential history and pointed out the importance of accurately measuring long-term exposure.

Green space. Green space and greenness show high strength in burst detection from 2018, indicating their importance in freshwater blue-health research. Green space is a recurring theme in blue-health research, and the relationship between them can be divided into three phases. In the first phase, blue space received little attention. Many studies regard blue space as an element of green space (Völker & Kistemann, 2011), always using terms such as green space (Laumann et al., 2001; van den Berg et al., 2016) and natural environments (Han, 2003) to refer to green and blue space collectively. With the formation of numerous significant research projects and the re-emergence of interest in the water-health relationship in the field of geography, the study of blue space and health became a distinct research topic in the second phase (McDougall et al., 2020). In the third phase, following the development of blue-health research, blue space is defined as 'health-enabling places and spaces, where water is at the centre of a range of environments with identifiable potential for promoting human well-being' (Foley & Kistemann, 2015). Therefore, blue space comprises the body of water and related environments. Green space can be an integral aspect of the surrounding environment of blue space, and recent research indicates that most people in freshwater blue space engage in land-based activities rather than water-based recreation (Elliott et al., 2018; Pasanen et al., 2019). Moreover, recent studies have shown that, in some cases, considering green and blue spaces together can benefit human health more effectively (Haase, 2015).

2.5 Trending Topics in Current Research

In this section, several trending topics in freshwater blue-health research are identified and then viewed through a design lens. Cluster analysis can identify trending topics, and this research uses cluster analysis through VOSviewer and CiteSpace, respectively (Figure 2.4 and Figure 2.5). On the other hand, the co-occurrence analysis and co-cited analysis in CiteSpace are used as supplementary material to identify trending topics (Figure 2.6 and Figure 2.8). Moreover, overlay and density visualisations in VOSviewer could offer solid support for reflection (Figure 2.7 and Figure 2.10). Based on the synthetic analysis, three trending topics are summarised, including focusing on experience and usage, attaching importance to psychological outcomes, and paying attention to the health benefits for specific age groups.

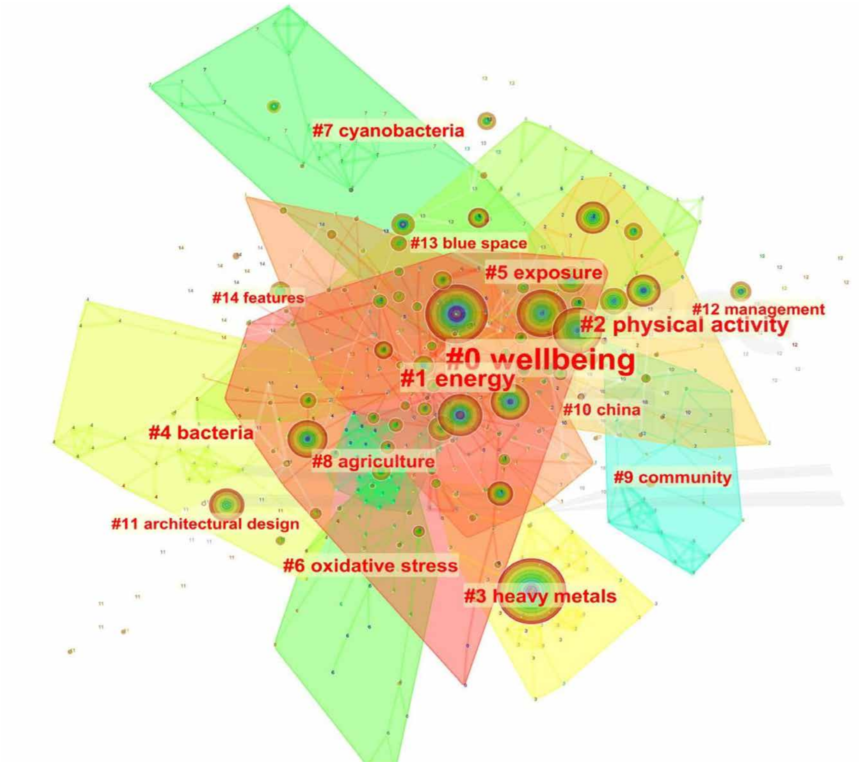


FIG. 2.4 Keyword-based Knowledge Clusters from CiteSpace.

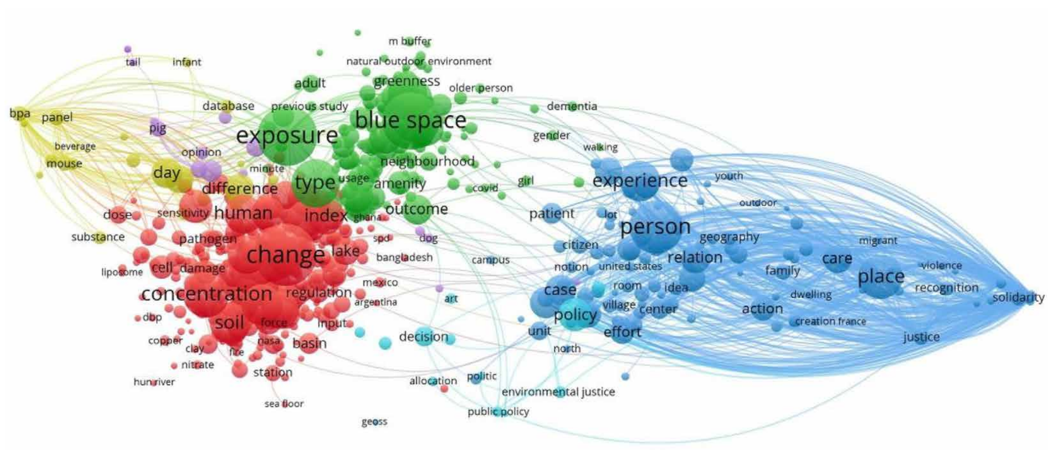


FIG. 2.5 Keyword-based Knowledge Clusters from VOSviewer.

TOC

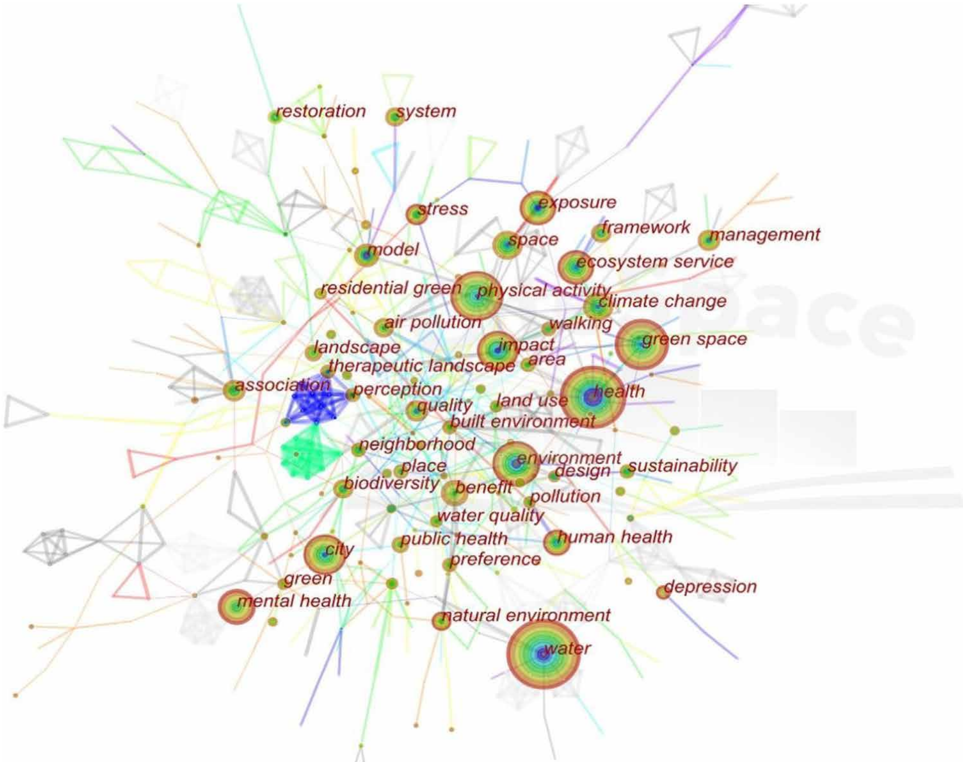


FIG. 2.6 Knowledge Mapping of the Keyword Co-occurrence Network.

2.5.1 Focusing on Experience and Usage

Although freshwater blue space provides many passive health benefits, including masking traffic noise (Jeon et al., 2010) and managing temperatures in the summer months (Völker & Kistemann, 2013), the use of freshwater blue space implies an intentional engagement with water, which is a more direct and critical approach for promoting health (Völker et al., 2018). The result of the overlay analysis in VOSviewer reflects the research development over time, and freshwater blue-health research before 2015 mainly focused on the physical environment (Figure 2.7). Some cyan and purple clusters of keywords demonstrate this trend, including pathogen, soil, copper, and substance. These studies discuss the role of health promotion in preventing the harmful effects of freshwater blue spaces, as water has previously been considered a breeding ground for various diseases (WHO, 2002). On the other hand, some researchers regard freshwater blue space as an effective way to optimise the ambient urban environment, positively affecting human health

(Shanahan et al., 2015; Völker et al., 2018; You et al., 2010). These two types of studies mainly focus on the intervention in the physical environment of freshwater blue space and are more related to natural science.

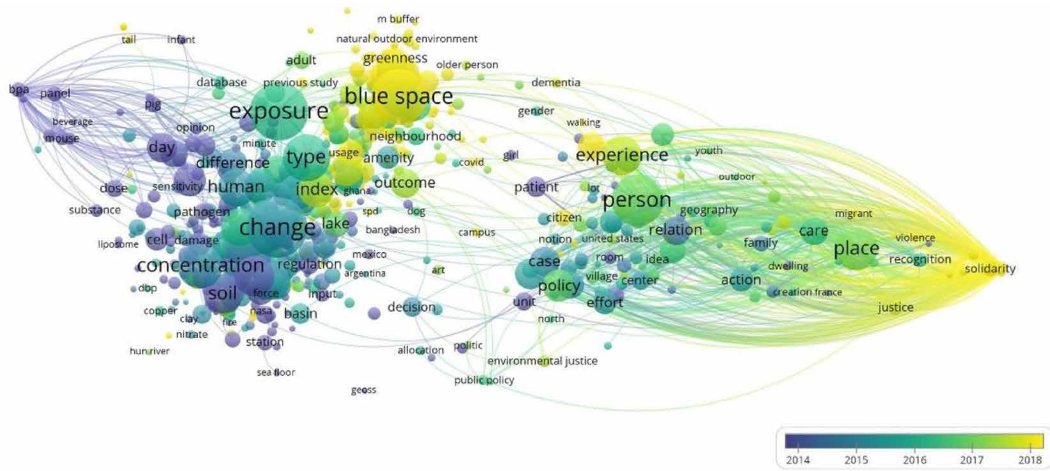


FIG. 2.7 Keyword Overlap Map from VOSviewer.

The yellow and light-green keyword clusters indicate that the focus of freshwater blue-health research has gradually evolved away from natural sciences toward social science (Figure 2.7). The research gradually focuses on human use and perceptions of the freshwater blue space, with related keywords including experience, usage, solidarity, and place. Although research on human health and freshwater blue space is in its early stages (McDougall et al., 2020), it shares certain similarities with the study on the natural environment, as blue space is a component of the natural ecosystem (van den Berg et al., 2016). Therefore, research on the natural environment and health can be adopted as a meaningful reference for research on freshwater blue space.

In nature-health research, the change in people's understanding of health has led to a considerable transformation (Hartig et al., 2014). With chronic, lifestyle-related health issues being the leading cause of death, the biopsychosocial explanation (Engel, 1977) has gained increasing attention and is viewed as a supplement to the biological paradigm. Alongside the changes in the definition of health, the methods for measuring health outcomes have also expanded, including previous indicators such as morbidity (Maas et al., 2009), mortality (Gascon et al., 2017), and longevity (Takano, 2002), and emerging indicators such as self-reported health (Pasanen et al., 2019) and cortisol levels after contact with nature (Gidlow, Randall, et al., 2016).

TOC

Biopsychosocial research focuses on how people perceive, assess, and use the natural environment. Related studies come from various disciplines, including epidemiology, environmental science, human geography, environmental psychology, urban studies, and landscape architecture (Hartig et al., 2014). Freshwater blue-health research also follows this trend. However, the total volume of research is still limited. In the future, this trend will be reinforced and consistent with other scientific research related to human health, where the natural and social sciences are often combined when certain stages of development are reached (VanLandingham, 2014).

2.5.2 Attaching Importance to Psychological Outcomes

The result of the document-based cluster analysis in CiteSpace is illustrated in Figure 2.8, which depicts several distinct research clusters based on the co-cited document network. It is noted that benefits related to psychological outcomes seem more important than physical activity in freshwater blue-health research. White et al. (2010) detect that water is associated with higher perceived restorative qualities when people view urban blue scenes than in other environments. Völker et al. (2018) take two German cities as cases to identify that blue space usage is related to mental health rather than physical health. Garrett et al. (2019) find similar results in a study of older adults in Hong Kong. Based on this, the document-based cluster analysis of green space is conducted for a comparative study with freshwater blue space. The results of the green space analysis show that physical activity plays a more critical role than psychological benefits (Figure 2.9). This finding aligns with a Canadian study examining the therapeutic impact of green and blue spaces for older adults (aged 65–86 years old) and finds that blue space, in particular, embodies important therapeutic qualities for mental health (Finlay et al., 2015).

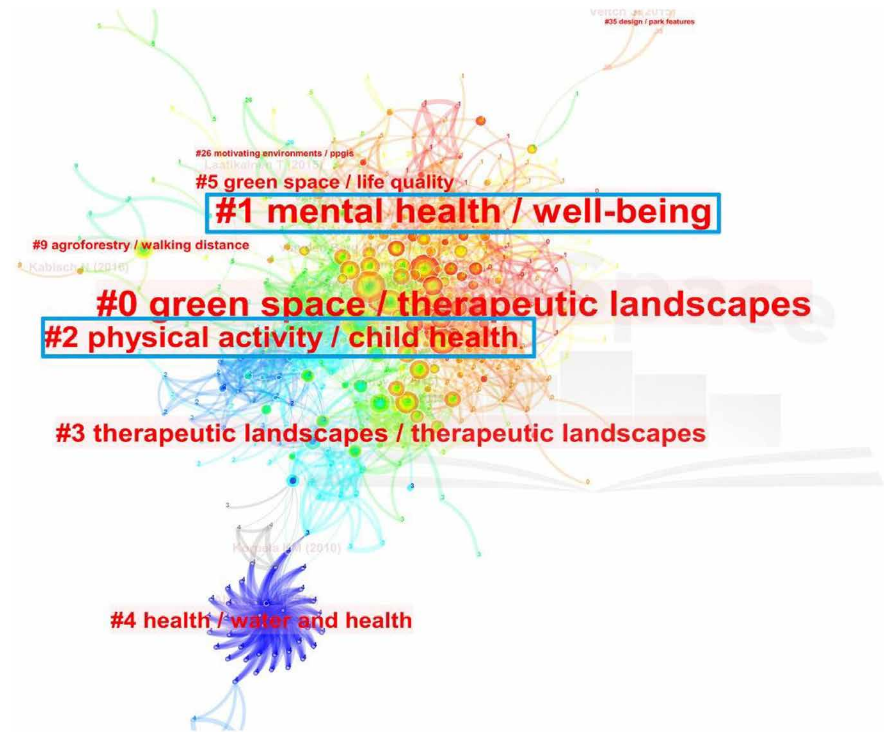


FIG. 2.8 Co-cited Document-based Knowledge Clusters from Freshwater Blue Space Health Research.

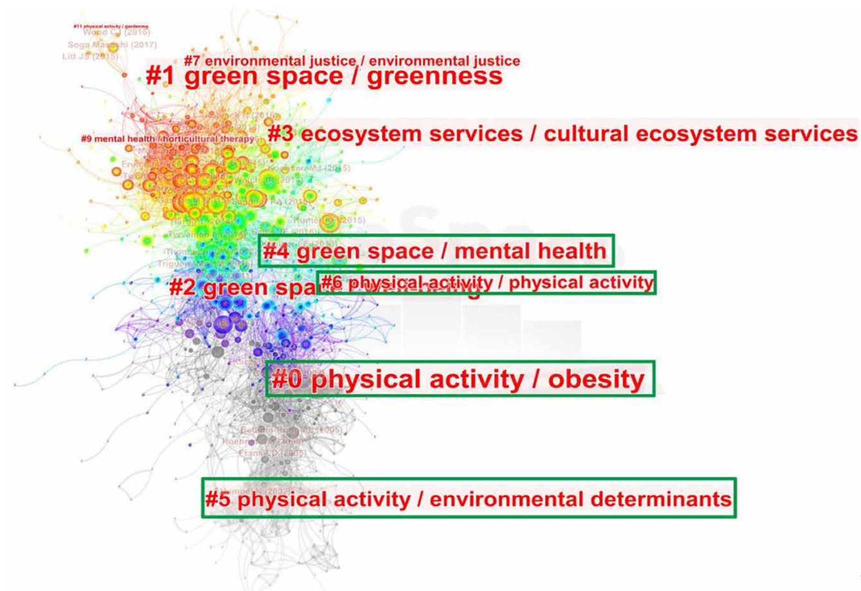


FIG. 2.9 Co-cited Document-based Knowledge Clusters from Green Space Health Research.

This study attempts to explain why research on freshwater blue space focuses more on psychological benefits. First, freshwater blue spaces can enhance mental health by acting as therapeutic or salutogenic spaces with a long history in various cultural contexts. The notion of a therapeutic landscape is inextricably linked to a psycho-evolutionary theory known as the biophilia hypothesis, which asserts that humans are born with an innate need to interact with nature and other life forms (Dempsey et al., 2018). Historically, blue space was regarded as a place of healing, including spas, baths, and other healing water spaces (Foley & Kistemann, 2015). Gesler's research on healing space describes that water could directly benefit health (Gesler, 1992, 1998).

Second, although blue space can offer a location for many types of recreation, most people prefer light land-based activities (such as walking, camping, and gathering) to water-based recreation. The health outcomes of these light activities are more related to psychological outcomes. For example, Völker & Kistemann (2013) find that many people enjoy sitting near the river and watching its movement, recognising the flowing water, the waves, the changing colour of the river, and other people's activities. Several studies have identified that blue views can benefit people's mental health, especially older adults with poor mobility (Coleman & Kearns, 2015; Dempsey et al., 2018; Helbich et al., 2019). Moreover, activities like camping and gathering in blue spaces may be particularly beneficial for positive social relationships, which are also a form of psychological outcomes. Many studies from several cultural contexts suggest that blue space can be ideal for spending time with friends and family (Foley, 2015; Vaeztavakoli et al., 2018; Völker & Kistemann, 2015).

Third, freshwater blue spaces can shield people against poor mental health (White et al., 2020). People are born with a strong need to connect with others or something bigger than themselves (Baumeister & Leary, 1995). Compared to green spaces, freshwater blue spaces like rivers and lakes are more likely to become the symbolic features of cities since green spaces are increasingly and easily encroached upon by construction (Bengston et al., 2004). Freshwater blue space may evoke people's sense of place and help them establish an attachment to a place and place identity. For example, the people in Cologne and Düsseldorf use the Rhine River to highlight and define their cities (Völker & Kistemann, 2013). Environmental psychologists suggest the beneficial and restorative effects of places on well-being (Kearns & Gesler, 1998; Lengen & Kistemann, 2012).

TOC

2.5.3 Paying More Attention to the Health Benefits for Specific Populations

According to the cluster analysis of CiteSpace and VOSviewer, there are several clusters related to specific populations, including older people, citizens, youth, and children (Figure 2.7 and Figure 2.8). These clusters show that freshwater blue-health research is gradually shifting toward specific populations. Some studies have identified this situation and called for attention to differences in health benefits among different population subgroups (Frumkin et al., 2017; Hartig et al., 2014; White et al., 2020), which have critical differences regarding access, use, and responses to nature that result from spatial, social, economic, ethnic, cultural, and demographic distinctions (Hartig et al., 2014). In studies on both green and blue spaces and health, researchers find that the health benefits of contact with green and blue spaces are more significant for poorer than wealthier individuals (Mitchell et al., 2015; Wheeler et al., 2012). These findings may shed light on the efficacy of green and blue spaces in alleviating socio-economic inequities (Hartig et al., 2014). For example, a study conducted in Spain examining the effect of pre/post-intervention on an urban river reveals that the spatial regeneration of rivers may reduce gender and ethnic inequality (Vert, Carrasco-Turigas, et al., 2019).

Further, some studies reported that men are likelier to visit freshwater urban blue spaces while women are more likely to enjoy coastal settings (Elliott et al., 2018; Vert, Carrasco-Turigas, et al., 2019). The activities people engage in when using blue space also differ significantly by gender and age, further influencing the mechanisms linking exposure and health. For instance, men prefer highly energetic activities and may benefit more from physical activities (White et al., 2020). Older adults with poor mobility may rely more on viewing the blue space to gain mental health benefits (Coleman & Kearns, 2015; Dempsey et al., 2018; Helbich et al., 2019).

Therefore, research on specific populations may provide three strengths. First, it can help avoid population-induced bias and render the results more convincing. Second, this kind of research can offer more detailed evidence to help researchers build a more comprehensive understanding of the relationship between freshwater space and health. Third, the evidence from different populations could provide a solid basis for designers and policymakers.

2.5.4 Reflections on Trending Topics from a Design Perspective

These trending topics reflect the demand for more in-depth research into the relationship between freshwater blue space and health while also benefiting design. Specifically, with a greater understanding of how people experience and use freshwater blue space, designers can better arrange space and facilities to improve freshwater blue space's health performance beyond a one-dimensional focus on quantity. In light of the growing emphasis on psychological outcomes, the health benefits of freshwater blue space design projects will be expressed beyond a singular focus on increased opportunities for physical activity. Thus, the toolbox for design could expand, as Völker & Kistemann (2013, 2015) reveal that many people gain psychological advantages from blue space simply by looking at water and interacting with others while enjoying a blue space. Moreover, the health benefits of exposure to freshwater blue space have often varied by population cohort and their perception of blue space. Understanding the health benefits of specific age groups, especially older people and children, can help designers develop a life-course approach. This approach, mentioned in Douglas et al.'s (2017) research on green space, provides opportunities to translate health evidence into design practice.

To conclude, these trending topics may be aligned with public engagement and people-centred goals in design fields (Delgado-Serrano et al., 2019; Wang, 2023). They provide a more robust argument for the health-oriented and evidence-based design approach, as research has demonstrated that design is critical in supporting human health and well-being (Sarkar & Webster, 2017).

2.6 Identifying a Vacuum in Freshwater Blue-health Research

Despite the growth of in-depth research into freshwater blue-health, a substantial research vacuum remains regarding the design perspective. From the conceptual framework in Section 2.2, existing studies mainly focus on the field of public health, including identifying health outcomes, summarising linking pathways, and collecting research evidence. However, less attention has been paid to research that emphasises design, including translating health evidence into design concepts, developing practical design knowledge, and applying these concepts and knowledge to real projects. While some studies have proposed methods and recommendations for freshwater blue space design to promote health, this is not always the case. Scientific research findings need to be translated into action (Brownson et al., 2018). Although current research can identify and quantify the health benefits of contacting nature, the research related to design interventions still urgently needs to determine what works well in practice (Kondo et al., 2015).

The results of the scientometric analysis reveal the research vacuum. According to the density map showing the occurrence frequencies of core keywords in VOSviewer, the clusters associated with action are dim, indicating that they have not received enough attention in freshwater blue-health research (Figure 2.10). In addition, according to the result of the keyword-based network analysis in VOSviewer (Figure 2.5), the light-blue keywords can be regarded as the action part for integrating health benefits into practice. Most of them are related to policy formulation or implementation, such as policy, politics, and public policy. These keywords imply that most studies seek to achieve the health benefits of freshwater blue space through policy advice, which corresponds to CiteSpace's cluster analysis (Figure 2.4), where the 'management' cluster conveys the same message.

However, even though policy measures are mentioned in some articles, they still receive insufficient attention. While numerous studies conclude with recommendations for policy and design initiatives, the majority of conclusions are broad and lack operability (Chen & Yuan, 2020; Garrett et al., 2019; Vert, Nieuwenhuijsen, et al., 2019; Völker et al., 2018). On the other hand, while actions related to policy and management can contribute to implementing research outcomes, design could be regarded as a direct and practical approach to improving blue space quality (de Bell et al., 2017). Although the cluster 'architectural design' is identified in the keyword-based cluster analysis of CiteSpace (Figure 2.4), research related to design remains scarce. Further, the keywords associated with 'architectural design' appear infrequently, and the cluster is not well-connected with others.

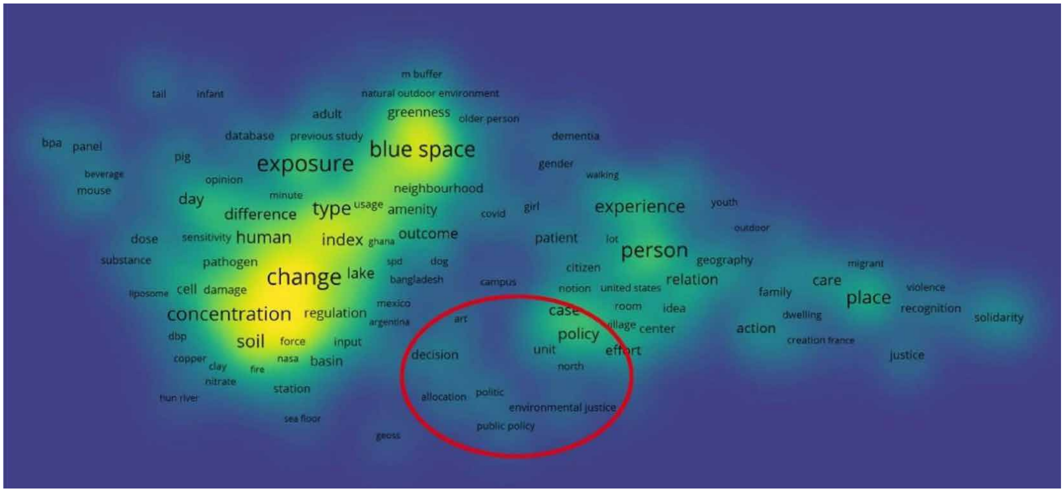


FIG. 2.10 Keywords Density Map from VOSviewer.

Generally, ‘design’ can be distinguished into a noun and a verb (Steinitz, 1995). As a noun, it represents the product of the design process in which the design is projected or implemented. From the perspective of viewing design as a noun, several existing studies have explored changes in the health-improving effect of freshwater blue space before and after design and developed some tools for assessing the health benefits of freshwater blue space (Bell et al., 2021; Mishra et al., 2021; van den Bogerd et al., 2021; Vassiljev et al., 2020; Vert, Nieuwenhuijsen, et al., 2019). The BEAT (BlueHealth Environmental Assessment Tool) and BBAT (BlueHealth Behavioural Assessment Tool) are the two representative tools that evaluate the health benefits of blue space and attempt to provide support for the implementation of future projects (Bell et al., 2021; Mishra et al., 2020). These tools are adopted before and after the design is created or implemented and can be used by multiple stakeholders, including designers, the public, policymakers, and government officials. However, the richness and quantity of such studies are limited in current research.

On the other hand, design as a verb refers to the act of projecting future environments through many types of representations, and it is mainly performed by designers (Nijhuis & de Vries, 2019). According to the analysis–synthesis–evaluation (ASE) paradigm, design could be considered an integrative practice where interactions among multiple stakeholders allow them to formulate design decisions (Braha & Maimon, 1997; Jones, 1992). The study of regarding design as a verb mainly focuses on generating practical knowledge, which emphasises the guidance of the design process and provides methodological support for fulfilling the design objectives. However, to our knowledge, few to no studies have explored the practical methodological support for designers to integrate health into freshwater blue space design. Therefore, building a bridge between existing research findings and the design process is necessary. The evidence/knowledge-based design approach can be a practical way to close this gap. The framework in Section 2.2 proposes a preliminary and bidirectional methodological approach for bridging the health evidence that receives wide attention and practical design knowledge that needs further elaboration in future research.

2.7 Conclusion

In recent decades, an increasing amount of research activities have been dedicated to exploring the health benefits of freshwater blue spaces to more effectively design healthy cities, which have gained significant prominence in implementing SDGs and health promoting agenda (WHO, 2020). Therefore, a comprehensive overview of the relationships among freshwater blue space, health, and design is needed to understand the current research progress and identify gaps. This chapter first proposed a six-step bidirectional framework connecting the health evidence with design practice, which can be regarded as a reference for organising current research and the methodological support for evidence translation.

Next, this chapter studied 1,338 publications on freshwater blue-health research with the assistance of scientometric analysis, reflecting the results from the design perspective. From 2000 to 2021, the number of publications in this area increased rapidly with broad collaboration among different disciplines. Environmental science, occupational health, and environmental studies have remained the dominant fields. The establishment of multidisciplinary research projects indicates policymakers' growing interests. After the keywords-based analysis, three main research categories were distinguished: mechanisms linking freshwater blue space and human health, different health benefits of exposure to freshwater blue space, and global challenges. Urbanisation, long-term exposure, and green space were robustly cited in the past three years, indicating the frontiers in freshwater blue health research.

Then, three trending topics in this area were summarised: (1) focusing on experience and usage, (2) attaching importance to psychological outcomes, and (3) paying attention to the health benefits for specific age groups. These trending topics could provide more robust arguments and the basis for a health-oriented and evidence-based design approach. Based on the conceptual framework and scientometric analysis, this research identified the main research gap: a lack of explorations from the design field. This kind of design research could provide a basis for assessing the health impacts of design interventions, as well as practical guidance or knowledge for integrating health benefits into the freshwater blue space design process.

This chapter can help comprehensively demonstrate the status of current research, guiding subsequent chapters. Moreover, it can facilitate multiple applications of health evidence by practitioners, including the development of HIA or EIA and guidance on the design process. However, this study has some limitations. First, the data was downloaded from the WoSCC using only English publications, resulting in a linguistic bias and neglecting other databases. Given the nature of the studies and the authors' preferences, some design-related studies may not be included in WoSCC. Second, although the main research gap has been identified, this chapter does not investigate it in detail, only presenting a conceptual framework and some preliminary discussions. Subsequent chapters could shed more light on the design perspective to facilitate the practicality and operability of health evidence.

3 Healthy Blue Space Design

A Methodological Framework for Translating the Health Benefits of Blue Space into Design Practices

This chapter outlines four main pathways linking exposure to/contact with blue spaces and human health: (1) improving ambient physical environments, (2) enhancing physical activity, (3) benefiting psychological outcomes, and (4) promoting social interaction. Subsequently, a four-step methodological framework is proposed, providing a practical approach to translating health evidence into practical design knowledge through the integration of existing data and case studies. The steps comprise: (1) distilling critical health evidence, (2) summarising key design concepts, (3)categorising the core design themes, and (4) translating these into design principles, spatial patterns, and evaluation methods. Finally, following the 'analysis–synthesis–evaluation' design paradigm, this chapter extensively explores the integration of practical design knowledge derived from health evidence into iterative design processes.

3.1 Introduction

Existing studies have demonstrated that exposure to or contact with blue spaces in urban contexts could significantly enhance human health (Pasanen et al., 2019; White et al., 2020; H. Zhang et al., 2022). Consequently, urban blue spaces are increasingly recognised as a pivotal element and public health resource in developing and constructing healthy cities (Bell et al., 2021; Hunter et al., 2023). While academic interest in the health benefits of blue spaces is increasing, researchers have primarily come from disciplines such as geography, environmental psychology, and public health (de Keijzer et al., 2019; Garrett et al., 2019; McDougall et al., 2021; Pasanen et al., 2019; Smith et al., 2021). Their studies have examined the correlation between various scales of health data and individuals' exposure to blue spaces, establishing conceptual frameworks and laying the groundwork for future causal inference.

In contrast to theoretical explorations, disciplines closely intertwined with design practice, such as urban planning, landscape architecture, and urban design, are notably underrepresented in current research (Rydin et al., 2012). The WHO underscores that existing health evidence is sufficient to inform practice, advocating for the active collaboration of practitioners and scholars in action-oriented fields to translate health evidence into actionable strategies (WHO, 2021). This research gap is also highlighted in the previous chapter, underscoring the need for interdisciplinary engagement. Nevertheless, several challenges hinder the translation of health evidence into design practice, including bridging the gap between the abstract nature of evidence and the practical realities of design, dealing with the intricacies inherent in the design process, and navigating the complexities of multidisciplinary collaboration introduced by knowledge/evidence-based design paradigm and the RtD approach (Nijhuis & Jauslin, 2015). Therefore, it is imperative to develop a methodological framework that can effectively translate existing evidence into practice.

To raise awareness of the health benefits of blue space and address existing research gaps, this chapter presents a methodological framework for translating health evidence related to blue space into applicable spatial design knowledge: (1) briefly summarising four main pathways linking blue space and human health, (2) developing and representing the methodological framework translating health evidence into design knowledge through case studies, and (3) reflecting on the potential of the methodological framework and translated design knowledge in design processes.

3.2 Main Pathways Linking Exposure to/ Contact with Blue Spaces and Human Health

In the previous two chapters, four main pathways linking blue space and human health have been briefly mentioned. This section provides in-depth content and evidence pertaining to these pathways, which could serve as public health–oriented components of the methodological framework. Following the framework delineated in the previous chapter and other conceptual frameworks, the foundation of health benefits derived from blue spaces lies in individuals' contact and exposure to such environments. Subsequently, several potential pathways connecting blue space exposure with health are generated, each ultimately contributing to human health (Figure 3.1).

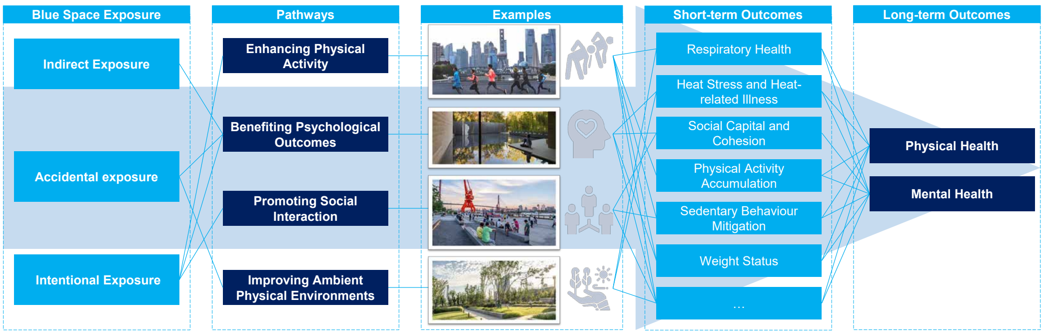


FIG. 3.1 Four Main Pathways Linking Blue Space Exposure and Human Health.

Based on existing studies, three types of blue space exposure/contact are conceptualised: (1) indirect exposure, encompassing instances where individuals encounter blue spaces without physically being present, such as through windows or television programmes; (2) accidental exposure, which pertains to casual encounters with blue spaces, such as passing by them during commutes; and (3) intentional exposure, involving purposeful visits to blue spaces, such as engaging in recreational physical activities or embarking on family outings in blue spaces. Next, four pathways linking blue space exposure/contact are summarised: (1) improving ambient physical environments, (2) enhancing physical activity, (3) benefiting psychological outcomes, and (4) promoting social interactions. Subsequently, the four main pathways and their respective evidence are presented below.

3.2.1 Improving Ambient Physical Environments

Existing research shows that blue space can improve the environment and reduce harm in multiple ways, including regulating urban temperatures, alleviating air pollution, preventing environmental noise, and enhancing immune functions (White et al., 2020).

Regulating urban temperatures. With global climate change and the effects of urbanisation, studies have already shown that urban heat island (UHI) effects and heat stress pose severe threats to health, well-being, and comfort (Kovats & Hajat, 2008; Sarkar & Webster, 2017; Tan et al., 2010). A Spanish study shows that areas within 4 km of the urban blue space had lower mortality than areas outside 4 km, indicating the capacity of urban blue spaces to mitigate heat-related mortality among older adults (Burkart et al., 2016). The temperature regulation of freshwater blue spaces reveals that blue spaces absorb heat when the air temperature exceeds the water temperature during the day and release heat at night when the water temperature exceeds the air temperature (Gunawardena et al., 2017). One review quantifies the temperature-mitigating effects of urban blue space by comparing 27 sites in the northern hemisphere, and the meta-analysis suggests that urban blue space leads to an average cooling effect of 2.5K from May to October (Völker et al., 2013).

Preventing environmental noise. Noise is ubiquitous in daily life and causes various adverse health effects. Environmental noise is receiving attention worldwide and has been regarded as a primary stressor in the urban environment, leading to annoyance, sleep disturbance, cardiovascular disease, and the impairment of cognitive performance in children (Basner et al., 2014). Existing studies have shown that green space can effectively reduce the noise level through diffraction, absorption, or the destructive interference of sound waves (Markevych et al., 2017; Van Renterghem et al., 2015). In most freshwater blue spaces, freshwater and vegetation (or green space) are often intertwined (Gascon et al., 2017; McDougall et al., 2020). Therefore, freshwater blue space could share the noise reduction mechanism of the green space. In addition, freshwater blue space may alleviate the harmful effects of noise by adding aquatic sound, which may have the opposite effect of vegetation (White et al., 2020). Some studies have claimed that water sounds have greater potential to reduce stress than urban sounds or even calming music (Thoma et al., 2018). In the urban context, however, water sounds are always accompanied by other sounds, including birdsong and other environmental sounds (natural sounds or even traffic noise). Studies have concluded that water-based sound is better for health when combined with pleasant sounds – even in a noisy environment, water sounds have the potential to improve people’s sound rating of the environment (Annerstedt et al., 2013; White et al., 2020).

Alleviating air pollution. Globally, ambient air pollution is the second most significant risk factor for the global disease burden. The mortality rate associated with it is expected to increase from 50% to 70% (Forouzanfar et al., 2016). Like reducing environmental noise, freshwater blue space alleviates air pollution by using both the surrounding vegetation and bodies of water capabilities. Some studies have shown that trees and other vegetation can affect air quality in two ways (Hartig et al., 2014). First, vegetation may directly reduce some pollutants, including gases and particulate matters (PM) (Frumkin et al., 2017). Second, it could reduce the need for air conditioning in the summer by providing shade, thus indirectly minimising the air pollution derived from coal combustion (Hartig et al., 2014). In addition, freshwater blue spaces, such as rivers and lakes in the urban environment, are always regarded as excellent locations for forming wind corridors that could increase air exchange to mitigate urban heat island effects, reduce haze events, and help solve other environmental problems (Ren et al., 2018).

Enhancing immune functions. Studies have explored the possibility that exposure to the natural environment enhances immune functions, suggesting that it may improve on two different time scales (Frumkin et al., 2017). Freshwater blue space may be consistent with the natural environment. First, freshwater blue space may contain some substances that modify immune functions over the human lifespan. Several studies have shown that the specific microclimate of waterfalls with high levels of ionised water aerosols may benefit lung function in a long-lasting way (Gaisberger et al., 2012; Grafetstätter et al., 2017). According to Elliott et al.'s (2018) research, walking or sunbathing could be the main recreational activities in both coastal environments and freshwater blue space. Ultraviolet radiation from regular walking or sunbathing in freshwater blue space could lead to a higher level of Vitamin D, which is related to several diseases, including autoimmune diseases, cardiovascular diseases, and certain cancers (Cherrie et al., 2015). Based on the hygiene hypothesis or old friends mechanism, freshwater blue space is a critical source of microbial biodiversity. Long-term exposure to it may optimise our immune systems by providing microbial input (Rook, 2013). Second, the short-term immune function enhancement mechanism of exposure to blue space may be consistent with green space, which is associated with improved natural killer cell activity (Frumkin et al., 2017; Li et al., 2010).

TOC

3.2.2 Enhancing Physical Activity

Insufficient physical activity is a major global health problem (Hallal et al., 2012). Regular physical activity plays a positive role in preventing and treating many non-communicable diseases (Lee et al., 2012) and benefits mental health and well-being (Fox, 1999), especially in the urban environment. Both experimental and observational studies indicate that the environmental setting may pose a significant impact on the health outcomes of physical activity, and outdoor environments, especially natural environments, could be more intensively related to health benefits than indoor settings (Mitchell, 2013; Pasanen et al., 2019). Thus, blue space's potential for encouraging physical activity has been widely discussed.

Some early studies from Australia and New Zealand show that the proximity of blue space is associated with a higher level of physical activity (White et al., 2020). Subsequent studies show similar outputs: the closer people lived to blue space, the more intense and likely they were to engage in physical activity (Perchoux et al., 2015; Vert, Nieuwenhuijsen, et al., 2019; White et al., 2014). Although limited studies have reported inconsistent results (Ying et al., 2015), most studies suggest that there are greater levels of physical activity among people who have better access to blue space (Gascon et al., 2017).

Apart from frequency and intensity, the different types of physical activities performed in blue space could also affect health outcomes. Compared to green space, blue space can provide unique physical activities and recreation, such as swimming, surfing, and boating. However, some studies suggest that the main benefits of blue space originate from land-based outdoor activities, especially walking or running (Elliott et al., 2018; Pasanen et al., 2019). Research from England finds that while people who live closer to blue space seem more likely to participate in water-related activities, fewer people actually do (Pasanen et al., 2019), and this research aligns with the field observation of the riverside in two German cities (Völker & Kistemann, 2013). Moreover, another England study indicates that people tend to spend more time on light land-based activities in coastal settings than green spaces (Elliott et al., 2015).

3.2.3 Benefiting Psychological Outcomes

Stress is considered one of the most critical factors associated with ill health in contemporary daily life, causing sleep problems, loss of appetite, constipation, and other health concerns (Grahn & Stigsdotter, 2003). According to Hartig et al.'s (2014) research, nature can reduce the risk of illness caused by stress and promote many intermediate health benefits in two ways: (1) reducing the exposure to some specific stressors and (2) restoring people's adaptive resources. The first approach is discussed in the environmental improvement section. Regarding restoration ability, there are two influential theories, attention restoration theory (Kaplan & Kaplan, 1989) and stress reduction theory (Ulrich et al., 1991), which explore why nature has more remarkable restorative qualities than other environments.

Attention restoration theory (ART) suggests that nature can counter mental fatigue and improve concentration when people spend time in natural settings. Directed attention fatigue will occur when the human brain focuses on specific tasks for a long time. ART holds that exposure to nature promotes more effortless brain function and reduces stress by stimulating involuntary attention and reducing directed attention (Hedblom et al., 2019; Kaplan & Kaplan, 1989). As White et al. (2020) argue, few studies have specifically focused on the potential of blue space to restore depleted cognitive abilities. They often include blue space in their research process but neglect it in the final discussion. However, the results of these studies are heterogeneous. One experimental study shows that visual and auditory stimuli in blue space may not improve the outcome of cognitive tasks compared to stimuli in urban scenes (Emfield & Neider, 2014). Elsewhere, Gidlow, Jones, et al.'s (2016) study compares the psychological and physiological responses of unstressed individuals after 30 minutes of walking in different environments. The authors find that blue spaces are associated with a greater restoration experience and sustained improvements in cognitive function that lasted 30 minutes after leaving the environment. Other studies have found similar results but do not specify blue space, holding that natural environment views or sounds may lead to participants performing better on cognitive tests (Berman et al., 2008; Van Hedger et al., 2019).

Stress reduction theory (SRT) emphasises psycho-evolutionary theories and argues that natural environments with vegetation and water are beneficial for humans living over thousands or millions of years since these environments provide resources and the ability to foresee predators. Such settings may potentially reduce the psychological and physiological symptoms caused by stress (Ulrich, 1984; Ulrich et al., 1991). In Ulrich's (1981) experimental study, he showed slide samples to subjects and measured the effects of these slides through alpha amplitude, heart rate, and emotional states. The results show that natural views' positive impacts on

TOC

psychological states are more significant than urban scenes, especially environments with water, which have more influence. In a subsequent study, Ulrich et al. (1991) further explored the relaxing power of natural environments and posited the SRT. Inspired by the work of Ulrich and his colleagues, many methods and instruments have been adopted to more precisely describe blue space exposure and the degree of stress improvement. MacKerron & Mourato's (2013) and Jansen et al.'s (2018) studies use satellite positioning (GPS) locations to assess blue space exposure. In Vert et al.'s (2020) research, 59 office workers are assigned to take a 20-minute walk in a specific environment for a week, and they find significant improvements in well-being and mood responses immediately after walking in blue space. Their results are consistent with several similar studies showing that walking in blue space leads to better emotional responses (Gidlow, Jones, et al., 2016; Jeon et al., 2010; White et al., 2020).

On the other hand, some short-term indicators are used to measure the participants' acute responses with and without exposure, including salivary cortisol levels, heartbeats, and skin conductance (Gidlow, Jones, et al., 2016; Hedblom et al., 2019). In addition to these physiological indexes, other measures take a little longer, such as subjective stress level and ability to cope with tasks (Frumkin et al., 2017). It is noted that de Vries et al. (2021) and MacKerron & Mourato (2013) attempt to shorten the measuring time and adopt a smartphone app to measure the momentary subjective well-being (SWB) of participants. Their studies find that participants are substantially happier in natural environments, and the effects of freshwater blue space are similar to those of green space.

3.2.4 Promoting Social Interactions

One of the main mechanisms of linking green space and human health is to improve social interactions. A growing body of research suggests that blue space appears to be more effective in promoting social interactions than green space (White et al., 2020). Vaeztavakoli et al. (2018), through a case report of the canal, show that a canal area is an ideal place for gathering among families and communities. A qualitative study from Germany obtains similar results. However, it also suggests that interactions with others are more common in blue spaces than in spaces traditionally considered more suitable for engaging with acquaintances (Völker & Kistemann, 2015). The involvement of others contributes to forming place/nature connectedness, as environmental psychologists prove that attachment to a place has restorative effects on human well-being. Another qualitative study conducted by Völker & Kistemann (2013) suggests that visitors experience a strong sense of place by the rivers of two German cities. It indicates that place/nature connectedness seems more intensive in blue space than in green space.

TOC

3.3 A Methodological Framework Translating Health Evidence from Blue Space into Design Knowledge

While gathering cross-regional and multi-perspective evidence remains challenging, the four pathways and the compiled evidence presented above illustrate the potential to offer direct assistance to design practice. Consequently, this section endeavours to formulate a methodological framework that connects health promotion regarding exposure/contact with blue spaces to spatial design practices, serving as an initial effort to address the existing research gap. The framework comprises six steps (Figure 3.2): (1) identification of the four pathways linking blue space exposure and health, as mentioned in the previous section; (2) review of existing studies to distil essential health evidence corresponding to the four pathways; (3) summary of the gathered health evidence into key design concepts; (4) subsequent categorisation of these design concepts into four core design themes; (5) translation of the design themes into practical design knowledge; (6) application of the design knowledge to spatial practices.

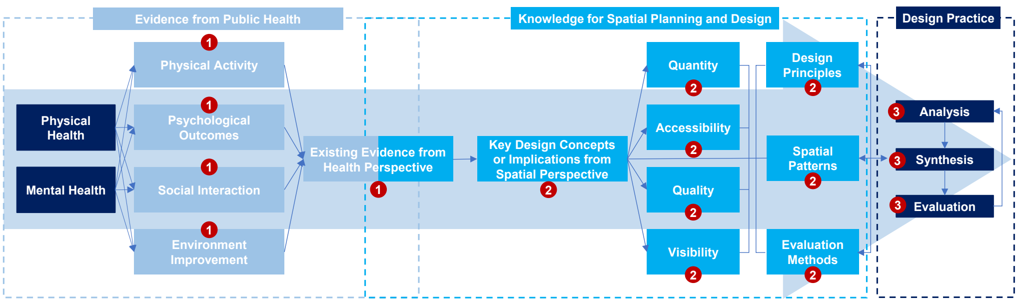


FIG. 3.2 A Methodological Framework Linking Health Evidence to the Spatial Design of Blue Spaces.

The framework's contributions are three-fold. First, the framework represents a bidirectional interaction between evidence and practice, moving beyond a linear process. It commences with health evidence of blue space exposure and concludes with practical applications. Conversely, robust practices and innovative solutions could inspire the exploration of evidence. Second, encompassing public health evidence, spatial planning/design knowledge, and project implementation/management, it explores the entire process from health evidence to design practice,

TOC

fostering collaboration and exchange. Third, while primarily addressing the design implementation of blue space health benefits, it offers insights applicable to evidence translation across various domains. In the subsequent section, the study exemplifies the outlined framework through case studies, explicitly emphasising steps 2 to 5. This part delves into the process of translating health evidence into practical design knowledge.

3.3.1 Distilling Critical Health Evidence

The evidence-distilling process predominantly relies on core publications identified within the papers gathered in the previous chapter. Source information includes the title, keywords, abstracts, and other pertinent details, filtering out those incongruent with the research theme or deemed less pivotal. Furthermore, a select few highly cited publications are added, culminating in a final selection of 57 publications for the distilling process.

Subsequently, the core information from selected publications is subjected to meticulous analysis, covering aspects such as study design, types of blue space exposure/contact, health benefits, related pathways, and primary research results. Based on the core information, design-related health evidence from the chosen publications can be distilled. For instance, a reproductive observational study in Plymouth, UK, explores shifts in visitor well-being pre/post-blue space interventions, indicating varied strategies correlating with heightened individual well-being and satisfaction (van den Bogerd et al., 2021). Then, health evidence is distilled from its research findings, including providing direct water access and reducing vehicle presence near blue spaces, contributing to heightened life satisfaction among visitors, fostering place attachment, and involving the public in design processes, enhancing well-being and life satisfaction among residents. Similar analyses are conducted separately for the core publications collected in this study (Table 3.1).

TABLE 3.1 Examples of Collecting Core Information from the Selected Publications.

Reference	Year	Journal	Study Design	Type of Blue Space Exposure
Vert et al., 2020	2020	Environmental Research	Crossover study	Beach, Urban, Indoor Walking
Völker et al., 2018	2018	Urban Forestry and Urban Greening	Cross-sectional study	Freshwater blue space in two cities; Walking
van den Bogerd et al., 2021	2021	Landscape and Urban Planning	Repeat cross-sectional study	Urban blue space Pre/ Post-renovation; Daily Use
Poulsen et al., 2021	2021	Landscape and Urban Planning	Nested case–control study	Urban blue spaces
White et al., 2021	2021	Scientific Reports	Cross-sectional study	All types of blue space in 18 cities
Fisher et al., 2021	2021	Science of The Total Environment	Cross-sectional study	Freshwater blue space, River
McDougall et al., 2021	2021	Landscape and Urban Planning	Cross-sectional study	Freshwater blue space Costal blue space
Pasanen et al., 2019	2019	Environment International	Cross-sectional study	All types of blue space in England

Health Outcomes	Pathway	Implications for Design	Design Concepts
Mental health Physical health	Psychological outcomes (Main) Physical activity	1. Increasing walking accessibility 2. Improving walking conditions on the beach	1. Accessibility 2. Quality
Mental health SF-12v2	Psychological outcomes	1. Improving walking conditions for daily use 2. Health benefits of the large-scale blue space 3. Health benefits of blue space view	1. Accessibility 2. Quality 3. Visibility
Mental health WHO-5, Life satisfaction	Psychological outcomes (Main) Social interaction	1. Increasing walking accessibility 2. Improving the safety of the environment 3. Increasing public space 4. Co-design and public participation	1. Accessibility 2. Quality (Safety, Quantity) 3. Design Process
Physical health Type 2 diabetes onset	Psychological outcomes Physical activity	1. Increasing road accessibility 2. Improving physical conditions of blue space 3. Avoiding the flooding risk 4. Improving the overall quality of blue space	1. Accessibility 2. Quality (physical conditions, flood risk)
Mental health WHO-5, Antidepressant medication prescribed	Psychological outcomes	1. Increasing possibility of recreational visits of blue space 2. Improving visual and auditory effects 3. Enhancing naturalness in blue space	1. Accessibility 2. Visibility 3. Quality (naturalness, recreation support)
Mental health Perceived restorativeness, Momentary wellbeing	Psychological outcomes	1. Preventing noise from the road 2. Increasing bio-diversity, especially birds 3. Improving the sense of safety (varied by cultures) 4. Focusing on natural sounds of blue space	1. Quality (bio-diversity, safety, prevent noise, natural sounds)
Mental Health Antidepressant medication prescribed	Psychological outcomes	1. Increasing freshwater coverage 2. Increasing the range within 10 minutes walking distance 3. Increasing visual and auditory exposure of blue space 4. Reducing barriers to entry into space in micro-level 5. Focusing on the psychological benefits of the large scale freshwater blue space	1. Quantity 2. Accessibility 3. Visibility 4. Quality (barriers, scale)
General Health Mental Health GHQ-12	Psychological outcomes Physical activity (Main)	1. Increasing the opportunities of walking alongside the large-scale water bodies 2. Improving the visibility of blue space, especially for the large-scale water bodies	1. Visibility 2. Quality (Walking conditions)

TOC

3.3.2 Summarising Key Design Concepts

Building upon the distillation of information from publications, the health evidence is further converted into design concepts related to spatial design. For instance, drawing on the previous case study, evidence indicating the provision of direct water access and the reduction of vehicle presence could be converted to improvements in hydrophilicity and the increased safety of blue spaces (van den Bogerd et al., 2021). Applying similar logic and methodologies, the research systematically converts the gathered evidence. Experts from the research team are then invited to review the results, ensuring the accuracy and validity of the conversion process. Following this step, the study aggregates all design concepts and utilises word cloud analysis to assess their significance, laying the groundwork for subsequent steps (Figure 3.3). The font size within the word cloud denotes the frequency of each concept in the literature. For instance, offering physical activity support emerges as the predominant concept, aligning closely with the pathway wherein blue space exposure fosters health benefits through enhancing physical activity.

FIG. 3.3 Word Cloud of Spatial Design Concepts.

3.3.3 Categorising Core Design Themes

While numerous design concepts have been delineated in the previous section, some are redundant or overlapping, necessitating refinement for practical application. Hence, the study proceeds to systematically categorise and integrate these concepts into five core design themes, drawing inspiration from several existing frameworks: spatial accessibility, spatial visibility, quantity, spatial quality, and design process (Figure 3.4). Specifically, accessibility, visibility, and quantity represent objective descriptions of blue space features, as numerous studies demonstrate that objective exposure and passive perception of blue space can yield significant health benefits (Dempsey et al., 2018; Nutsford et al., 2016; Yin et al., 2023). On the other hand, spatial quality is closely tied to subjective perception and may vary across cultures, profoundly influencing individuals' experiences and utilisation of space (McDougall et al., 2020).

The four themes encompass various subclasses of the design concepts identified earlier. For instance, accessibility comprises walking accessibility, public transport systems, road networks, and hydrophilicity. Among these, enhancing walking accessibility, public transportation systems, and road networks aims to reduce difficulties in contacting blue spaces from various dimensions, corresponding to spatial interventions at the medium/macro levels. Hydrophilicity, however, emphasises facilitating direct human-water contact at the micro level. Next, this study illustrates the translation of these four core design elements into practical design knowledge by incorporating case studies.

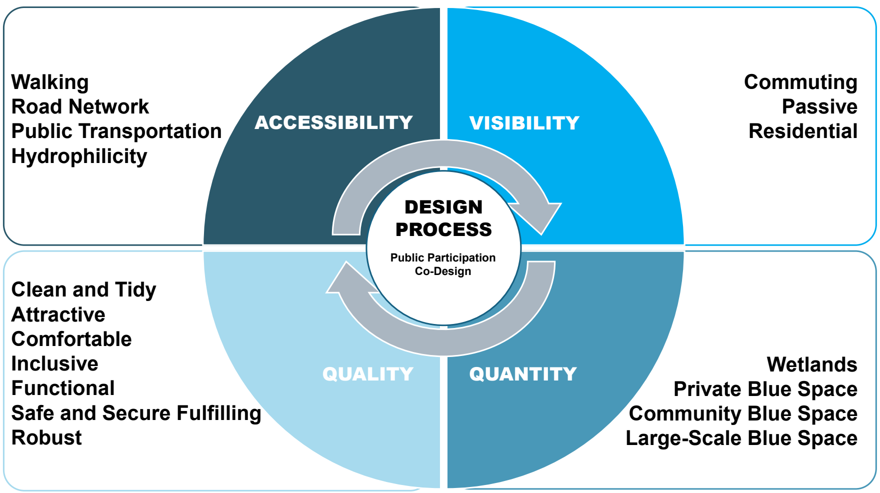


FIG. 3.4 Categorising Spatial Design Concepts into Five Main Themes.

3.3.4 Translating into Practical Design Knowledge

Practical design knowledge is mainly concerned with solving spatial problems, which practitioners can directly apply to projects through targeted site integration. Its forms vary based on scale, including design principles, guidelines, planning strategies, and spatial patterns. Well-known examples include Durand's analysis of architectural typologies, the five points of new architecture proposed by Le Corbusier, and Christopher Alexander's pattern language (Figure 3.5). However, as the knowledge/evidence-based design paradigm evolves and RtD approaches have gained prominence, traditional design knowledge based solely on principles or strategies is no longer adequate to address contemporary practical demands. Incorporating evaluation methods and site-specific evidence is essential to validate the efficacy of potential design knowledge.

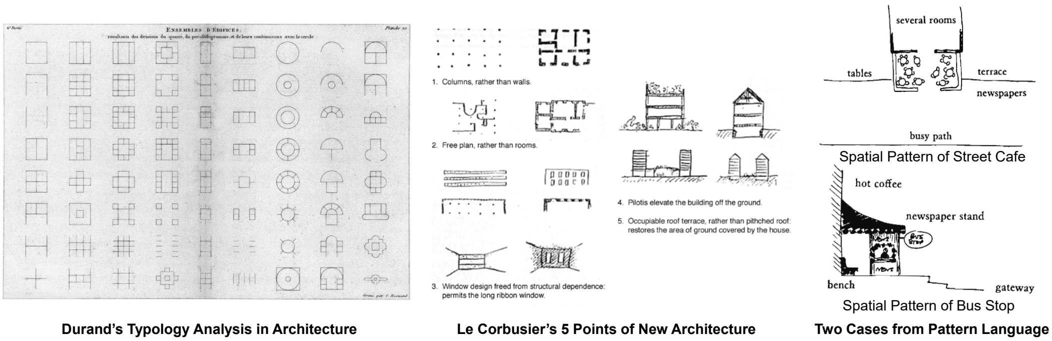


FIG. 3.5 Examples of Design Knowledge; From Left to Right: Durand, 1805; Corbusier, 1926, Alexander, 1977.

This study further translates the above four design themes into practical design knowledge, including design principles, spatial patterns, and evaluation methods. Among them, design principles and spatial patterns offer direct guidance for designers in developing spatial solutions. As mentioned, design principles are general and broad, while spatial patterns are explicit and specific. Additionally, evaluation methods assist practitioners in analysing the current site situations and refining potential solutions throughout the design process. In the rest of the section, this study employs multi-scale cases to illustrate the design principles, spatial patterns, and evaluation methods derived from the four design themes. For the design knowledge related to three design themes emphasising objective description (i.e. quantity, accessibility, and visibility), this study presents both design principles and spatial patterns alongside evaluation methods. Specifically, the design principles and spatial patterns are derived from precedent studies and design common sense.

Further, the evaluation methods incorporate interdisciplinary knowledge and tools. For the design knowledge of spatial quality focusing on subjective experience, the research focuses on generating design principles and spatial patterns based on on-site analysis. Notably, cases presented in this section are intended to demonstrate the methodological framework, and the following sections show the details of the development of each type of design knowledge.

Figure 3.6 [1–3] illustrates three design principles aimed at increasing the quantity of blue space: (1) expanding current bodies of water, (2) revitalising the existing/historical bodies of water, and (3) creating new freshwater blue spaces. As exemplifications, each design principle is conceptualised into two specific spatial patterns. For instance, expanding current bodies of water could be converted into two spatial patterns: (1) enhancing the development of current rivers and (2) revitalising historical water systems. Furthermore, this study presents two methods and their respective application frameworks for analysing and evaluating blue space quantity, tailored to different data types: (1) calculating the modified normalised difference water index (MNDWI) using remote sensing images and (2) assessing blue space distribution through land-use maps and field surveys (Figure 3.6 [4–5]). These two methods facilitate rapid measurement and evaluation of blue space quantity changes after applying the corresponding design principles and patterns. The method selection does not emphasise technological sophistication but rather data availability and practical applicability.

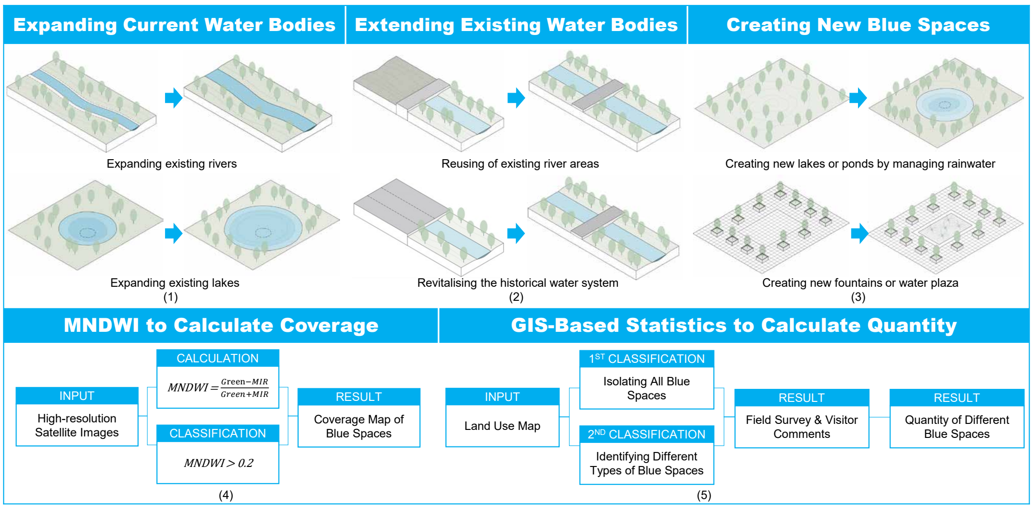


FIG. 3.6 Examples of Design Knowledge for Improving Spatial Quantity.

TOC

Following a similar rationale, figure 3.7 [1–3] shows three design principles for enhancing blue space accessibility: (1) optimising the main road structure, (2) adjusting the internal road network of blue spaces, and (3) enhancing the hydrophilicity of water edges. Compared to improving quantity, enhancing accessibility entails more intricate principles and patterns, often spanning multiple scales. To capture this complexity, the three principles delineated here pertain to regional, district, and local scales. The study presents two spatial patterns for each of them, such as enhancing connectivity of internal roads and placing roads near and over bodies of water as spatial patterns for adjusting internal road networks.

Accordingly, to evaluate the accessibility of blue space at different scales, three evaluation methods are presented, demonstrating their applications with the Rotterdam cases (Figure 3.7 [4–6]): (1) gravity-based two-step-floating catchment area (G2SFCA) method for assessing blue space accessibility at the regional scale; (2) using online map API to evaluate accessibility at the district scale; and (3) accessing digital models for accessibility at a local scale. These methods illustrate the outcomes of evaluating and analysing blue space accessibility across various neighbourhoods through visualisations. Practitioners can directly obtain information from the results to aid in formulating spatial interventions. For instance, the G2SFCA results depict variations in blue space accessibility across different neighbourhoods, which could be used to assess changes in accessibility following adjustments to the overall road structure in line with the proposed principles and patterns.

Figure 3.8 [1–3] presents three design principles for improving blue space visibility from different scales with corresponding spatial patterns: (1) reserving urban viewing corridors; (2) optimising the spatial layout of surrounding blocks; (3) increasing water viewing facilities. Similar to accessibility, three helpful methods for measuring visibility at three scales are illustrated (Figure 3.8 [4–6]): (1) cumulative viewshed analysis summarising by neighbourhoods and population density; (2) 3D Isovist analysis evaluating blue visibility of several buildings adjacent to the Rotte River; and (3) segmentation analysis of several riverside photos. These methods could also provide support for practitioners in developing spatial interventions. For instance, the real-time simulation of the 3D Isovist method could be employed to assess changes in the blue visibility of buildings within blocks after modifying the spatial layout of these blocks.

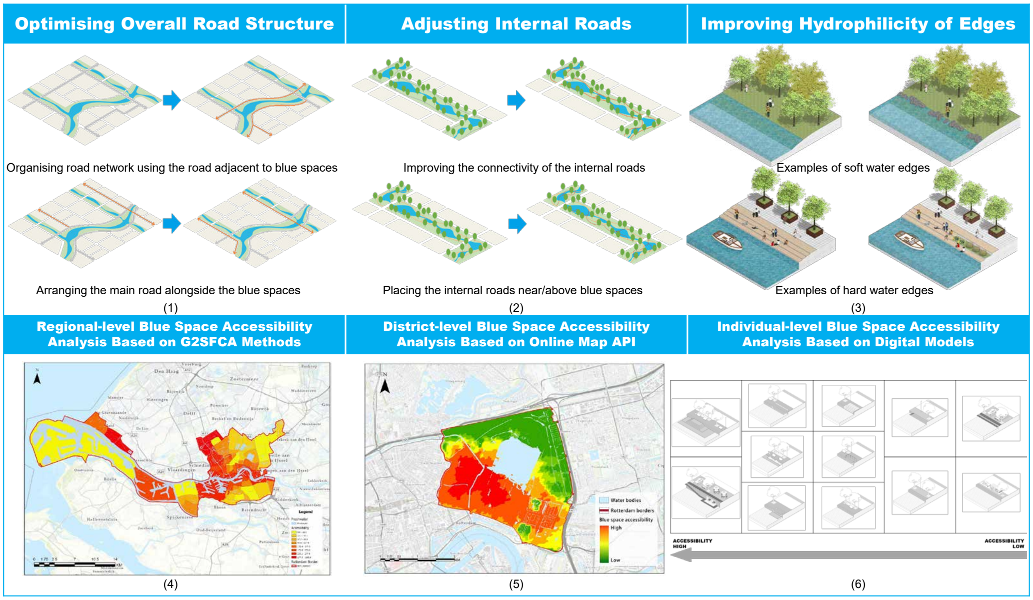


FIG. 3.7 Examples of Design Knowledge for Improving Spatial Accessibility.

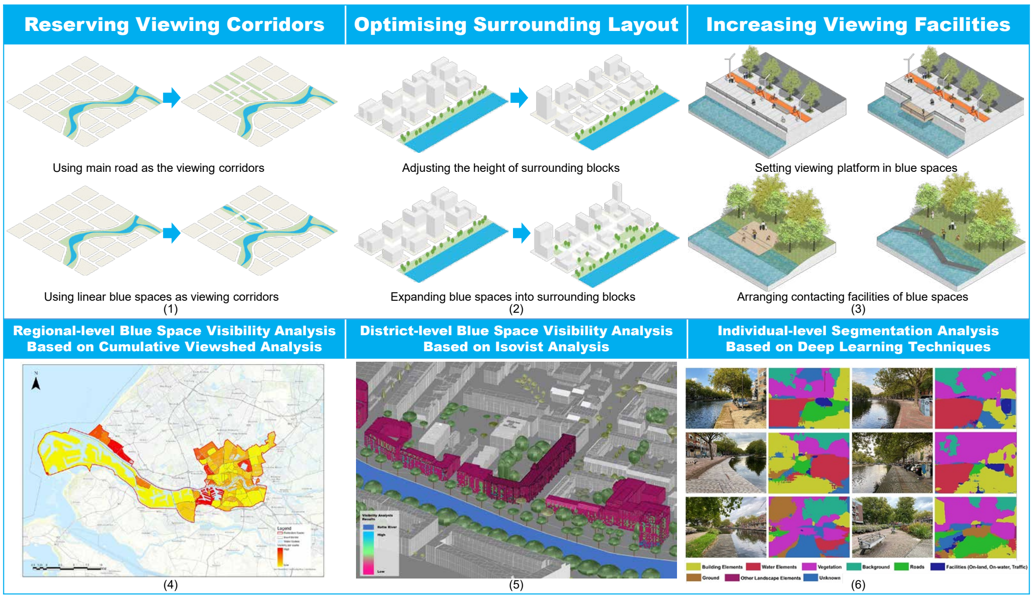


FIG. 3.8 Examples of Design Knowledge for Improving Spatial Visibility.

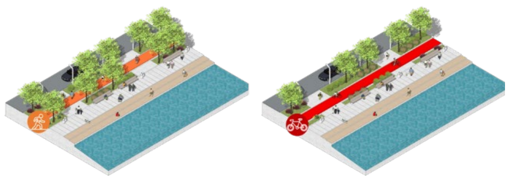
Figure 3.9 [1–2] presents two design principles for improving blue space quality: (1) planning cycling/running routes based on the specific type of blue space and (2) designing walking routes in blue spaces should introduce more vegetation exposure compared to cycling routes. Since principles of improving spatial quality should be closely connected to the local context, the proposed principles are not dependent on existing literature or cases but are translated according to an analysis of local data. In brief, the study obtains street-level recreational physical activity data (i.e. running and cycling) of Rotterdam's blue space from the Strava platform, representing the health effects of blue spaces.

At the same time, Google Street View images of blue spaces are collected for segmentation analysis, and several street-level spatial quality features of blue spaces are calculated (Figure 3.9). Then, utilising various regression models, the correlations between the spatial quality features of blue spaces and the number of recreational physical activities are analysed, providing the basis for the formulation of design principles. Some results show that (1) vegetation exposure promotes both cycling and running but has a more significant effect on running; (2) people prefer to run in blue spaces with recreational functions and ride in the linear blue spaces. Accordingly, the research puts forward the above two design principles.

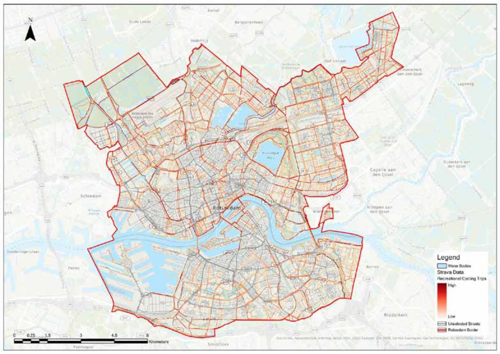
The above overview provides insight into the process and outcomes of converting the four core design themes into practical design knowledge, serving to elucidate the methodological framework. Subsequent chapters (i.e. Chapters 4–6) delve into the generation and outcomes of this design knowledge in detail. Indeed, the formulation of design principles and spatial patterns relies on health evidence while also embracing the creative spatial interpretations of designers. Consequently, they can be considered open-ended results, with research practitioners refining them as new evidence emerges. Next, this chapter briefly explains the final component of the methodological framework: the application potential of design knowledge within the real design process and practices.

Arranging Running/Cycling Routes Based on Blue Space Types

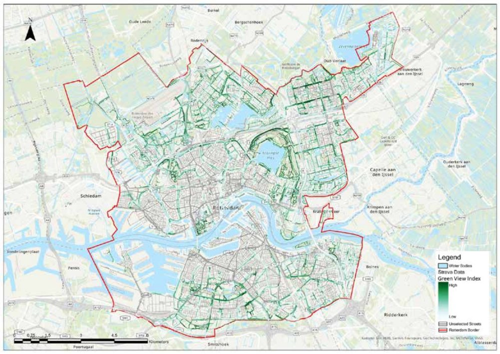
Considering Vegetation in the Design of Running/Cycling Routes



Count of Recreational Cycling in Blue Spaces of Rotterdam Based on Strava Data



Green Exposure of Blue Spaces in Rotterdam Based on Street View Images and Machine Learning Techniques



An Example of Correlation Analysis Results of Blue Space Quality and the Counts of Recreational Running/Cycling Based on OLS and Spatial Regression Models

	Recreational Running						Recreational Cycling					
	OLS		Spatial Lag		Spatial Error		OLS		Spatial Lag		Spatial Error	
	S. Coef.	S. E.	S. Coef.	S. E.	S. Coef.	S. E.	S. Coef.	S. E.	S. Coef.	S. E.	S. Coef.	S. E.
Adjacent to inland canal	Reference		Reference		Reference		Reference		Reference		Reference	
Adjacent to Maas River	0.980**	0.053	0.631**	0.047	1.080**	0.087	0.470**	0.065	0.379**	0.059	0.646**	0.103
Adjacent to recreational water	0.080*	0.029	0.035	0.026	0.179**	0.044	-0.658**	0.035	-0.367**	0.032	-0.410**	0.053
Green View Index (GVI)	0.155**	0.015	0.142**	0.013	0.222**	0.016	0.056*	0.018	0.071**	0.017	0.115**	0.020

FIG. 3.9 Examples of Design Knowledge for Improving Spatial Quality.

3.4 The Design Process: A Tool for Framework Application and Reflection

3.4.1 Incorporate Practical Design Knowledge into Real Design Iterations

In general, the process of spatial design could be divided into three phases: analysis, synthesis, and evaluation (Braha & Maimon, 1997; Jones, 1992). The practical design knowledge illustrated in the previous section could be incorporated into these three phases (Figure 3.10). Specifically, the evaluation methods play a crucial role in both the analysis and evaluation phases, while design principles and spatial patterns could be applied during the synthesis phase. During the analysis phase, evaluation methods aid designers in understanding the current site conditions and identifying areas requiring intervention. Subsequently, leveraging the site conditions and design objectives, designers utilise the design principles and spatial patterns as guidelines to develop targeted solutions. These principles and patterns then serve as general design knowledge, while the tailored design solutions represent specific design knowledge.

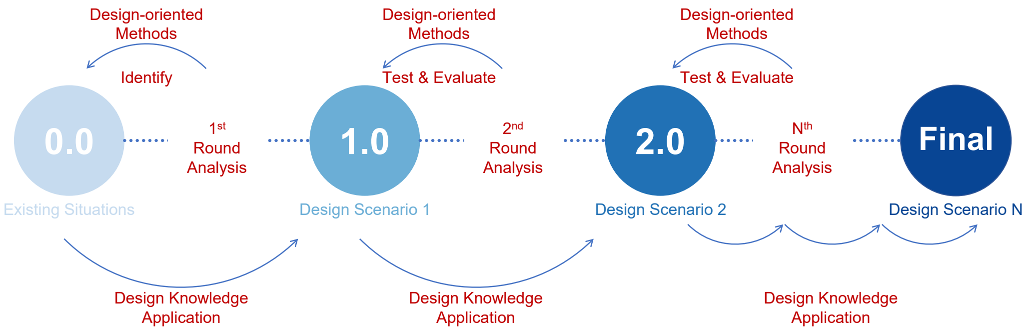


FIG. 3.10 Incorporating Design Knowledge in Iterative Design Processes.

Design thinking is integral to the whole process as it empowers designers to creatively solve problems, moving beyond the mere replication of general design knowledge (Nijhuis & de Vries, 2019). The evaluation methods are subsequently reapplied in the evaluation phase to assess the effectiveness of the solutions and offer insights for further refinements. In practice, the evolution of final solutions reflects a systematic search by designers across various possibilities; thus, the aforementioned phases are often conducted multiple times, constituting an iterative design process.

On the other hand, this practical design knowledge serves not only to facilitate the design process but also functions as a tool for communication among diverse stakeholders and enhances long-term project management. For instance, specific indicators derived from evaluation methods could aid in environmental monitoring, some digital tools could facilitate comparisons between different design schemes during multi-stakeholder communications, and the design principles and spatial patterns could be utilised as a menu tool for improving public engagement and implementing a participatory design approach.

3.4.2 Inspire New Design Principles and Spatial Patterns via Design Practices

In applying design knowledge to spatial practices, the bidirectional nature of the methodological framework grows clear. As previously discussed, the designer's implementations of principles and patterns are not straightforward repetitions but rather creative illuminations. It involves integrating site analysis, design intuition, experience, judgment, and other factors, refining the concept with various design objectives, and ultimately shaping specific spatial solutions (Nijhuis & de Vries, 2019). In several instances, the designer's implementation may yield unexpected surprises, offering innovations that complement the existing toolbox, expand the new principles and patterns, and inspire researchers to delve into more detailed evidence explorations.

3.5 Conclusion

Exposure to or contact with blue spaces could bring considerable health benefits, which is becoming a critical approach for constructing healthy cities and implementing SDGs. Building upon the preliminary evidence and framework outlined in the previous chapter, this chapter initially outlined four pathways between blue space exposure and human health. Subsequently, it established a methodological framework for systematically translating health evidence into design knowledge, illustrated through multi-scale cases. Finally, this chapter reflects on the iterative design process of integrating design knowledge into practice. The findings of this chapter offer methodological underpinnings for the research in subsequent chapters and a tangible framework for health evidence translation. Moreover, they encourage further studies to proactively apply the framework to other aspects of healthy city construction and evidence translation.

Several limitations persist in this study. Firstly, this chapter, and even subsequent ones, only presents a portion of the design principles and spatial patterns, focusing on the rationale behind their development. Consequently, a comprehensive list is not feasible, necessitating that future practitioners compile and augment them through practical applications. Second, regarding the design knowledge concerning spatial quality, this study exclusively offers insights gleaned from specific cases and evidence. However, certain potential design elements – such as detailed spatial organisations and seasonal variations – as well as the generalisability of existing evidence to other locations warrant further exploration. Third, while the subsequent chapters have partly validated the practicality of the framework and the translated knowledge through design experiments and expert interviews, its replicability remains limited, particularly when addressing complex spatial design objectives. Future endeavours should entail extensive applications of the framework and design knowledge to thoroughly assess their potential and shortcomings, particularly when combined with other design objectives.

PART II

Development of Qualitative and Quantitative Design Knowledge

In Part I, leveraging a comprehensive overview of blue-health research, this study developed a methodological framework aimed at bridging health evidence with design practice by scrutinising and synthesising existing evidence. The framework can be succinctly delineated into three primary components: first, the distillation and analysis of existing research evidence, as illustrated in Part I; second, the translation of health evidence into practical design knowledge; and finally, the application of the design knowledge in spatial practices. Part II elaborates on the second part of the framework, wherein precedent analysis, interdisciplinary tools, and site-based evidence translation are employed to derive design knowledge for fostering health-supportive blue spaces. Specifically, Chapter 4 introduces advanced digital methods for evaluating blue space accessibility, visibility, and quantity. Chapter 5 elucidates design principles and spatial patterns pertinent to accessibility, quantity, and visibility. Subsequently, Chapters 6 and 7 delve into the development of design knowledge concerning spatial quality, utilising site evidence from Rotterdam.

The contents of Chapters 4–6 six are also published in:

Zhang, H., Nijhuis, S., & Newton, C. (2023a). Uncovering the Visibility of Blue Spaces: Design-oriented Methods for Analysing Water Elements and Maximising Their Potential. Journal of Digital Landscape Architecture, 2023(8), 628–638. DOI: 10.14627/537740066

Zhang, H., Nijhuis, S., & Newton, C. (2023b). Advanced digital methods for analysing and optimising accessibility and visibility of water for designing sustainable healthy urban environments. Sustainable Cities and Society, 98(June), 104804. DOI: 10.1016/j.scs.2023.104804

Zhang, H., Nijhuis, S., Newton, C., & Tao, Y. (2024). Healthy Urban Blue Space Design: Exploring the Associations of Blue Space Spatial Quality with Recreational Running and Cycling Using Crowdsourced Data. Sustainable Cities and Society, 117(February), 105929. DOI: 10.1016/j.scs.2024.105929

Zhang, H., Nijhuis, S., Newton, C., & Shan, L. (Submitted to a peer-reviewed journal, under second round review). Running in Rotterdam's Blue Spaces: Age Group Preferences and the Impact of Visual Perceptions.

4 Analysing and Optimising the Accessibility, Quantity, and Visibility of Blue Spaces

Advanced Digital Methods for Designing Healthy Urban Environments

This chapter delves into advanced methods to effectively analyse and evaluate the spatial quantity, accessibility, and visibility of blue spaces, aiming to support practitioners in designing healthy blue spaces. Rotterdam is utilised as a test case, demonstrating the role of these methods in evaluating the performance of blue space quantity, accessibility, and visibility in urban environments, specifically in terms of spatial morphology and physical characteristics. Eight distinct methods are discussed, addressing measuring themes, scale levels, and design interactions, subsequently offering a novel flowchart for their integration into cross-scale spatial design and policymaking. The findings underscore the need to select appropriate methods to analyse and optimise blue space quantity, accessibility, and visibility in spatial planning or design assignments. The selection should be based on design intentions and data availability. The most considerable potential is found in combining these methods to handle the complexity of urban

issues. The research reveals the importance of blue space quantity, accessibility, and visibility in promoting healthy urban environments while also emphasising the need to go beyond them, factoring in the quality of blue spaces.

4.1 Introduction

Given the rising prevalence of chronic lifestyle-related diseases, global attention to urban health issues has intensified, positioning the creation of healthy urban environments as a major concern (Adlakha & John, 2022; Hua et al., 2022). As highlighted in Part I, blue spaces have received minimal scholarly attention but increasingly are regarded as practical solutions to cope with non-communicable diseases, offering multiple ecosystem services with social and environmental dimensions, effectively contributing to healthy urban environments (Kondo et al., 2015; Mapar et al., 2020; Megahed & Ghoneim, 2020; Ramaswami et al., 2016; WHO, 2017).

The previous chapter has identified and proposed methodological frameworks that translate health-promoting evidence of blue spaces into design practice. Specifically, by reviewing current evidence, the four design themes of blue spaces for fulfilling their public health benefits are identified, including spatial quantity, accessibility, visibility, and quality. Then, the practical design knowledge could be developed based on the four themes. Since spatial quantity, accessibility, and visibility emphasise objective spatial descriptions of blue spaces, the corresponding design knowledge of these three themes compass three parts, including design principles, spatial patterns, and evaluation methods. **This chapter will concentrate on the evaluation methods associated with spatial quantity, accessibility, and visibility, exploring their potential to aid the spatial design process.**

4.1.1 Methods for Describing Blue Space Quantity, Accessibility, and Visibility

Reviewing the existing studies reveals that multiple approaches are available to measure spatial quantity, accessibility, and visibility of blue spaces. The quantity of blue space, often referred to in many studies as blue space availability, is typically measured based on the area or presence of blue space within a specific geographical region (Thornhill et al., 2022). Consequently, the methods for evaluation and analysis are relatively straightforward, primarily relying on statistical index approaches, also known as area-based or container approaches. Specific indicators include total area, per capita area, blue space coverage, and cumulative kernel density estimation (Pasanen et al., 2019; Wu & Kim, 2021).

Existing studies on the accessibility of blue spaces or public facilities systematically categorised the methods of measuring spatial accessibility into three types (McDougall et al., 2020; Wang et al., 2021; Zhang et al., 2011): a) statistical index approaches, which describe and evaluate spatial accessibility based on the number of blue spaces; b) spatial proximity approaches or travel cost approaches that emphasise the travel costs between green/blue spaces and an individual's location, with specific indicators including linear/network distance, estimated travel duration, and self-reported distance/time (Hooyberg et al., 2020; McDougall et al., 2022); c) spatial interaction approaches, the extension of the gravity model, consider the supply-demand relationship of green/blue spaces and population to describe accessibility, and specific methods include gravity model analysis, 2SFCA, E2SFCA, and 3SFCA (Liang et al., 2023; Sharifi et al., 2021). Generally, these methods primarily rely on GIS for calculation, and some recent advanced techniques have shown great potential in integrating existing methods (Costa et al., 2021; Rothfeld et al., 2019; Wolff, 2021).

For spatial visibility, the viewshed method conducted in GIS is commonly adopted in current blue-health research to quantify visibility. Isovist analysis originates in architectural and urban analyses, which share a similar computational logic with viewshed. Some studies have demonstrated its potential to introduce 3D models of urban environments to describe visibility more accurately (Kim et al., 2019; Krukar et al., 2021; Morello & Ratti, 2009). In addition, segmentation analysis from computer vision is being widely used in measuring green exposure, while eye-tracking analysis has been used in many studies to describe visibility subjectively for exploring visual preference.

4.1.2 Knowledge Gap and Research Objectives

To date, only limited studies have mentioned or analysed the methods for measuring spatial quantity, accessibility, and visibility, and even fewer have explored their application potential in assisting spatial design. Specifically, McDougall et al. (2020) identify four types of methods for measuring blue space exposure and critically compare these methods to inspire subsequent research. Labib et al.'s (2020) research analyses the methods for describing spatial exposure used in nature-health studies from a broader perspective and appeals to the multi-scale methods to comprehensively understand nature exposure. These two studies primarily review existing methods and evidence rather than providing case applications to demonstrate the potential of each method. On the other hand, Liu & Nijhuis (2020) and Wang et al. (2021) adopt specific cases to compare and analyse the application of different methods. Derived from the study of green spaces, Wang et al. (2021) compare the methods for spatial accessibility and explore the interrelationships among them. Liu & Nijhuis (2020) take a similar view of this research by emphasising the method's potential in spatial design while reviewing spatial-visual characteristics from the larger landscape design perspective.

Although these studies provide valuable support, there remains a knowledge gap regarding these evaluation methods as design knowledge and exploring their potential in assisting design and planning, which has been outlined in the previous chapter. First, some practical methods for analysing quantity, accessibility, and visibility have been provided by existing studies, but the contents and indicators described by these methods are not systematically summarised and explored. Wang et al. (2021) compare the methods for the accessibility of green space, but limited articles focus on visibility. Second, due to the spatial nature of the methods, it is worth exploring how to practically apply them in spatial design and interpreting their application from the design perspective through real cases. Spatial design is a core activity in urban design, landscape architecture, and related disciplines, providing spatial solutions for fulfilling the health benefits of blue space exposure (Nijhuis & de Vries, 2019). Third, there are challenges in method selection and application guidance in combining the methods in multi-scale spatial design due to urban environments' complexity and dynamic nature (Nijhuis & de Vries, 2019). Only limited studies have explored the application of some of these methods in design practice (Bell et al., 2021; Mishra et al., 2020). Based on the ASE paradigm, designers require these methods to analyse existing site situations and evaluate the design outcomes (Braha & Maimon, 1997; Jones, 1992). Therefore, all of the above provide the necessary prerequisites for incorporating methods describing blue space exposure into spatial design (Figure 4.1).

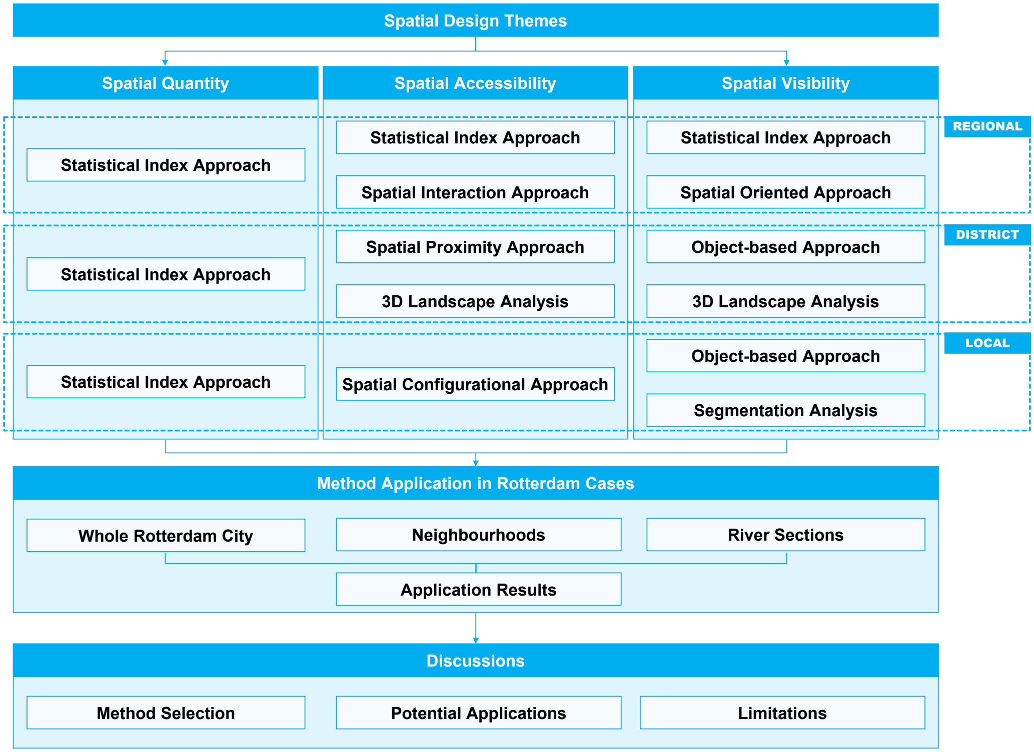


FIG. 4.1 Chapter Outline.

4.2 Methods for Evaluating and Measuring the Quantity, Accessibility, and Visibility of Blue Space

4.2.1 The Potential of Incorporating Methods of Measuring Blue Space Quantity, Accessibility, and Visibility in Spatial Design

As mentioned above, several methods have emerged to measure the quantity, accessibility, and visibility of blue spaces. Given the evaluative nature of these methods, they show great potential to assist in the design of blue spaces, which could parallel current research on better understanding the relationship between blue space and health benefits. As highlighted in the previous chapter, design is an iterative process and can be divided into three interconnected phases based on the ASE paradigm (Braha & Maimon, 1997; Jones, 1992; Nijhuis & de Vries, 2019). First, the analysis phase allows designers to collect knowledge or information from the existing context and identify the limitations or potential for subsequent steps. The synthesis phase refers to the process in which designers creatively propose solutions based on their analysis and communications with different stakeholders. Finally, the evaluation phase simulates and assesses the proposed solutions (Nijhuis & de Vries, 2019). A well-known example is the geodesign framework developed by Steinitz (2012), which combines GIS-based impact simulation methods with the creation of policies and design proposals. Methods for describing the quantity, accessibility, and visibility of blue space could play the same role by supporting policymakers and designers in the analysis, assessment/simulation, and communication during implementation.

4.2.2 Understanding the Role of Scale when Integrating the Methods of Measuring Blue Space Quantity, Accessibility, and Visibility into the Design Process

Scale is a critical concept when measuring blue space quantity, accessibility, and visibility and incorporating these factors into the design process, as is the case with current research on the relationship between blue space exposure and human health. For instance, the area-based method facilitates the investigation of health outcomes across varying levels of blue space accessibility and enables the evaluation of spatial equity concerning blue spaces at a regional scale. They are often analysed in conjunction with health data based on regional statistics (McDougall et al., 2020). On the other hand, scale is one of the core concepts in spatial design, distinguishing spatial design into many sub-categories, ranging from regional design to detailed building technology. Spatial design at different scales responds to specific questions, influences stakeholders' interests operating at that scale, and impacts other scale levels (de Jong, 2006).

Before integrating the methods into the design process, it is necessary to distinguish scales first. Otherwise, the paradox of scale can arise, in which conclusions made at one scale cannot be applied to another without concern (Gell-Mann & Mermin, 1994). To properly classify scales for incorporating methods into the design process, two existing spatial scale classification approaches, derived from spatial design and behavioural/cognitive geography, respectively, are introduced. The first approach was developed by de Jong (2006). From the spatial design perspective, his research divides physical space into six categories: regional design, urbanism, urban design, architecture, interior design, and building technology, which corresponds to the different physical sizes and in line with the recent '3–30–300 rule' for spatial planning aimed at fulfilling health benefits of green spaces (Konijnendijk, 2023; Nieuwenhuijsen et al., 2022). On the other hand, the classification of space proposed by Montello (1993), centring on people's psychological spatial perception, is included as the second source for distinguishing scales. By considering the human body's locomotion in space, Montello's classification focuses on the functional properties among different scales and distinguishes four main types of psychological spaces, including figural, vista, environmental, and geographical spaces (Montello, 1993).

Due to the continuous nature of physical space, different scales serve different objectives and are not entirely isolated but partially overlap. By incorporating these two classification approaches, an analytical diagram is proposed to develop a new simplified spatial classification, which helps explore the application of the blue exposure methods in the design process (Figure 4.2). Thus, a connection from the scale between psychological and physical space is established by setting psychological space scales as the horizontal axis and physical space scales as the vertical axis.

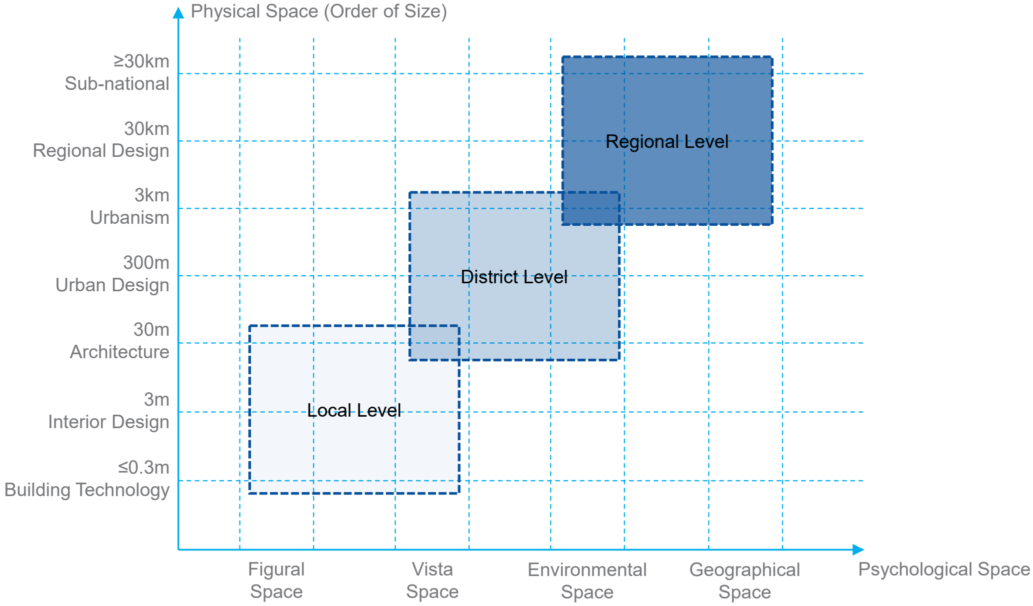


FIG. 4.2 Space Classification Based on the Existing Two Approaches (Developed Based on de Jong 2006 and Montello 1993).

For the sake of clarity, three new scales are defined, including local, district, and regional levels, each corresponding to physical and psychological space, respectively. Specifically, the regional level mainly refers to the sub-national, regional design, and urbanisation scale in physical space. In psychological space, it relates to the environmental and geographical space that cannot be perceived through people's movement. On the other side, the local level spans multiple scales of physical space, from building technology to architecture/landscape design, and can be perceived directly or through limited locomotion, which refers to figural and vista space according to the psychological space. The district level lies in the middle of the two. It ranges from architecture/landscape design to the urbanism scale in terms of physical space and corresponds to vista and environmental space in psychological space. At this level, space can be perceived by people through considerable movement. The simplified classification aligns with the existing '3–30–300 rule' in planning, which supports subsequent applications and interpretations of methods from spatial planning and design.

Similar to the existing classification approaches, which have fuzzy boundaries between scales, the boundaries of the new three levels are not distinct and contain some overlapping areas to improve the method's applicability potential and avoid the limitations caused by explicit categorisation. Specifically, the advantages are three-fold: (1) strengthening the continuous and dynamic nature of space, the importance of which has been pointed out in the existing space classifications; (2) providing flexibility in the choice of methods based on target audiences and participating stakeholders for some cross-scale projects; (3) supporting practitioners in making integrated decisions based on the evidence provided by different methods when projects are located in the overlapping areas.

4.2.3 Methods and Their Meanings for Measuring Blue Space Quantity, Accessibility, and Visibility at Different Scales

Reviewing the existing research outcomes on blue/green space exposure shows eight representative methods for describing blue space quantity, accessibility, and visibility, including the statistical index approach, spatial interaction approaches, spatial-oriented approach, spatial proximity approach, object-based approach, 3D landscape analysis, spatial configurational approach, and segmentation analysis (Dempsey et al., 2018; Helbich et al., 2019; Liu & Nijhuis, 2020; Ma et al., 2022; Nijhuis, 2015; Nutsford et al., 2016; Qiang et al., 2019; Ruzickova et al., 2021; Tannous et al., 2021; Wang et al., 2021; Yu et al., 2016; Zhou et al., 2019).

Notably, while spatial interventions to enhance the number of blue spaces can be implemented at various spatial scales, the approach used for measuring them remains relatively straightforward, primarily employing the statistical index method. The concept of spatial quantity expressed across different scales is consistent, with variations mainly manifesting in potential data accuracy. Therefore, the subsequent chapter will predominantly concentrate on spatial accessibility and visibility at three scales. The details of the statistical index approaches are discussed within the contents, addressing methods of accessibility and visibility at the regional scale. The details, meanings, and application potentials of the methods are briefly discussed below in accordance with the three scale levels just presented.

TABLE 4.1 Specification of Eight Methods for Describing Blue Space Quantity, Accessibility, and Visibility Based on Three Scale Levels.

Application scale	Methods	Design theme	Description	Main tools & platforms	Input data	Interactions with planning and design processes
Regional level	Statistical index approach	Quantity Accessibility Visibility	Using some indicators (e.g. total or mean area) within selected units to describe the accessibility or visibility of blue spaces	GIS[a], Excel	Land-use map; Satellite images	Pre/post-planning/design analysis
	Spatial interaction approach	Accessibility	Measuring accessibility by considering the supply-demand relationship	GIS, Excel	Land-use data; Population data	Pre/post-planning/design analysis
	Spatial-oriented approach	Visibility	Delineating the surfaces or areas which are visible to a set of observer features	GIS	GIS data (raster)	Pre/post-planning/design analysis
District level	Spatial proximity approach	Accessibility	Measuring the minimum travel time or distance or the number of blue spaces that can be reached within a certain time or distance threshold	Python; GIS; Online map platform	Road data (vector)	Pre/post-planning/design analysis
	Object-based approach	Visibility	Similar to the spatial-oriented approach, but with more focus on the polygon of visibility	Rhino & Grasshopper; Depthmap X	Rhino 3D models; CAD maps[b]	Scenario-based analysing tool
Local level	3D landscape analysis	Accessibility Visibility	Using photos or digital models to describe the exposure qualitatively	Camera; Rhino; SketchUp	Field survey; Photographs; 3D models	Scenario-based analysing tool
	Spatial con-figurational approach	Accessibility	Exploring the characteristics of spatial configuration to analyse whether the specific locations are easy to reach or pass through	Depthmap X; GIS; Pen & Sketchhbook	Field survey; CAD map (Road networks)	Pre/post-planning/design analysis
	Object-based approach	Visibility	Same as the descriptions above	Rhino & Grasshopper	Rhino 3D models; CAD maps	Scenario-based analysing tool
	Segmentation analysis	Visibility	Describing the types and proportions of landscape elements in the FOV quantitatively	Python; Excel	Photographs	Scenario-based analysing tool

a *GIS (geographic information system) refers to software applications used for capturing, storing, analysing, managing, and presenting geographic or spatial data, such as ArcGIS and QGIS.*

b *CAD (computer-aided design) maps represent the digital documentation and drawings of specific areas that are produced by 2D or 3D CAD programs such as AutoCAD and Rhino 3D.*

4.2.3.1 Regional Level

Space at the regional level cannot be perceived by people even through massive movements. It is mainly connected to regional or urbanism design projects, the outcomes of which are often abstract, such as policy recommendations and visions for future development. Accordingly, the statistical index approach, spatial interaction approach, and spatial-oriented approach could be suitable and applicable to spatial design projects at the regional level for describing accessibility and visibility (Table 4.1). Specifically, the statistical index approach measures the number, total area, or density of blue spaces within selected units (Chen & Yuan, 2020; Pearson et al., 2019; Wang et al., 2021). Generally, the statistical index approach is primarily associated with the number of blue spaces across all scale levels. However, when integrated with health data at the regional level, this approach can serve as an alternative means of representing accessibility or visibility (Boers et al., 2018; Crouse et al., 2018; White et al., 2021). It demonstrates considerable reliability because proximity to blue spaces often correlates with an increased likelihood of interaction with these areas (White et al., 2020). Its advantage lies in the simplicity and convenience of data acquisition, calculation, and explanations, allowing for evaluation under limited time or data and the quick communication of results with others. Its shortcomings consist of the difficulty in accurately describing blue space exposure and the modifiable areal unit problem (MAUP) when measuring accessibility (Wong, 2004).

On the other hand, spatial interaction and spatial-oriented approaches could provide more precise and direct measures of accessibility and visibility, respectively, with high-quality data availability and computing power. Spatial interaction approaches could avoid MAUP and generate accessibility measurements by incorporating population data and distance decay models (Tao et al., 2020; Wang et al., 2021). However, the distance decay model selection may influence the calculation results. Moreover, the spatial-oriented approach could be used to measure blue visibility at the regional level using cumulative viewshed analysis to calculate the total area of visible blue space in specific areas. Although it provides more accurate descriptions of visibility, the requirements of computing power and model quality (such as a high-resolution digital surface model) are much higher than the statistical index approach. For practitioners, all three methods allow comparison between different areas and pre-/post-interventions of sites to support the development of policies and design interventions.

4.2.3.2 District Level

The district-level space can be gradually perceived through locomotion, connecting the physical scales from urbanism to architecture/landscape design. Describing blue space accessibility and visibility at this level should consider people's movements, which are affected mainly by spatial morphological attributes and elements' arrangement. Therefore, the spatial proximity approach measuring accessibility and the object-based approach describing visibility could be adopted at this level. Specifically, the spatial proximity approach describes accessibility by measuring the travel cost of the nearest blue space or the amount of blue space that can be reached within a certain threshold (Wang, 2012). However, it could be influenced by destination selection and travel preferences, which assume that people prefer to use the nearest blue spaces (Wang et al., 2021).

Moreover, with the development of geo-big data approaches incorporating real-time traffic information and point-to-point distance calculations, it has become possible to analyse space-time accessibility through travel time estimations, which is more representative of individual behaviour and movement than accessibility on Euclidean/network-based distance (Costa et al., 2021; Su et al., 2017). The object-based approach, a three-dimensional (3D) visibility calculation, could represent the proportion of visible blue spaces to the observer's views during the specific movements. Compared with the viewshed analysis in GIS relying on 2.5D geometry, its advantage lies in using 3D models to describe blue visibility, which has a more accurate representation of vegetation and other elements (Ruzickova et al., 2021). Finally, the results of these two methods could be clearly demonstrated in visualisations to assist designers in the analysis and evaluation phases. The object-based approach could be used as a scenario-based tool, allowing designers to make rapid changes to represent and test new ideas.

4.2.3.3 Local Level

The local-level space emphasises people's direct perception without movement. It is closely related to projects of architecture/landscape design, interior design, and even building technology. Accordingly, the projects at this level emphasise specific spatial forms and their meanings, and the outcomes mainly include the spatial organisation of various landscape elements based on physics, function, and aesthetics (Nijhuis, 2015; Polat & Akay, 2015). Describing blue accessibility and visibility at this level often considers the influence of physical environments' specific configurational and compositional properties on people's direct contact with or view of blue spaces.

Therefore, the blue exposure at this level can be described and analysed using 3D landscape analysis, a spatial configurational approach, and segmentation analysis. More specifically, 3D landscape analysis is widely used by designers in daily practice to identify the characteristics of specific spatial arrangements using 2/3D visualisations (Liu & Nijhuis, 2020). It provides qualitative descriptions of accessibility and visibility based on spatial characteristics, which may be influenced by the designer's subjective interpretation. The spatial configurational approach could offer quantitative measurements of accessibility compared to 3D landscape analysis. It relies significantly on the interrelationship between human behaviour and urban surroundings, such as the notion of natural mobility, which argues that roadway layout affects city movement patterns (Hillier et al., 1993; Koohsari et al., 2019). Through exploring the spatial configurations, accessibility could be described as whether it is easy to reach or pass through a given location. Separately, the segmentation analysis mainly uses techniques and algorithms in computer vision to provide an objective description of blue space visibility, which calculates the number of different landscape elements and their proportion in fixed viewpoints. It is critical to note that 3D landscape and segmentation analysis are also scenario-based tools, allowing designers to test ideas quickly.

In brief, the eight methods are classified into three categories based on three scales and three design themes (i.e. mainly accessibility and visibility; see Table 4.1). The statistical index approach is well-suited for measuring visibility and accessibility at the regional level, as well as quantity across various scale levels. Meanwhile, the spatial interaction method is particularly effective for assessing blue space accessibility, while the spatial-oriented approach is focused on enhancing the visibility of blue spaces. At the district level, the spatial proximity approach can be utilised to describe blue accessibility, whereas the object-based approach can be employed for blue visibility. Additionally, at the local level, 3D landscape analysis can be considered a robust tool to describe both accessibility and visibility, similar to the statistical index approach. The spatial configurational approach is particularly suitable for evaluating accessibility, while the segmentation analysis focuses on blue visibility.

4.3 Case Study and Data Sources

4.3.1 Case Study Context

To showcase the applications of methods measuring three design themes of blue spaces (i.e. quantity, accessibility, and visibility) at different scales and how their results can be interpreted from the design perspective, several cases in Rotterdam are used as examples. Rotterdam, the second largest city in the Netherlands and Europe's major port, is located in Western Europe, which has a temperate oceanic climate (Figure 4.3). The city covers 326 km^2 and houses a population of over 600,000. It is a commercial and industrial hub at the Nieuwe Maas River, and its economy is heavily dependent on careful water control. The city is located on riverbanks, polders, and reclaimed land, and much of the city is below sea level (up to -6 m). Therefore, the city has wealthy blue space resources, including different types of natural and artificial waters, which account for 34.9% of the city's surface.

Consequently, the local government has implemented various plans to enhance the quality of green/blue spaces, underscoring their importance in the urban environment (Frantzeskaki & Tilie, 2014). Existing studies have reported the positive relationships between blue space exposure and health in Rotterdam, providing concrete evidence of its helpful selection as a case study (de Vries et al., 2003, 2016; Jansen et al., 2018; Luttik, 2000; White et al., 2021). Moreover, data availability and physical accessibility (i.e. fieldwork) contribute to evaluating the results and allow for reflection on their potential integration into design phases. As a result, Rotterdam is an important and representative case for exploring the potential of different methods.

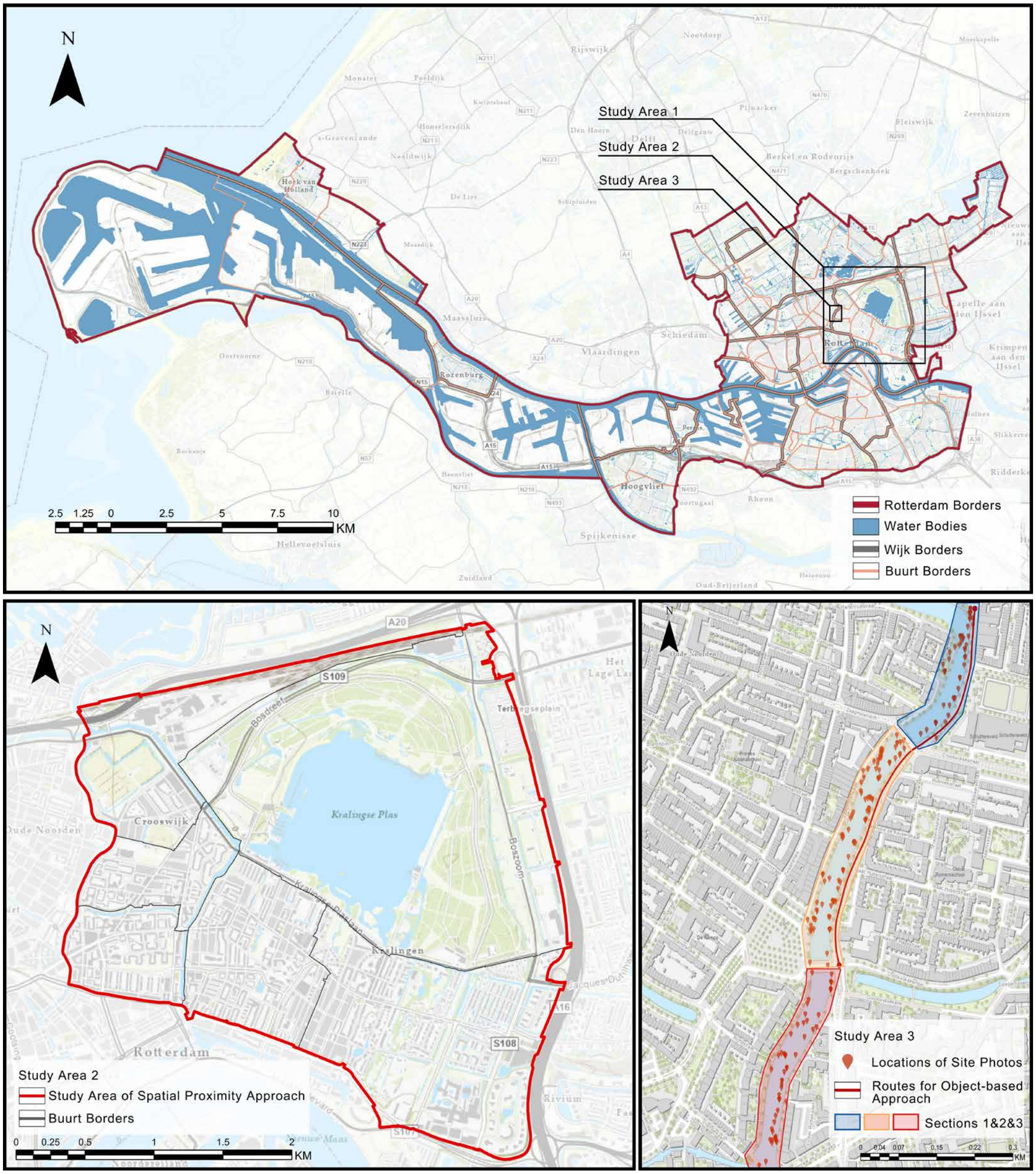


FIG. 4.3 Study Areas in Rotterdam.

4.3.2 Data Sources and Analysis Tools

Data used in the study areas are drawn from multiple sources (see supplementary materials of Zhang et al. 2023b for detailed information). Most vector data of spatial features is extracted from the BGT (Basisregistratie Grootschalige Topografie) database via the PDOK platform. The raster data of Rotterdam for visibility analysis at the regional level mainly adopts the digital surface model (DSM) with 0.5m resolution, which develops on laser altimetry from AHN (Actueel Hoogtebestand Nederland) and captures the height information of the city surface, including non-ground level objects (e.g. trees, buildings). The raw road network data are sourced from the OSM dataset (OpenStreetMap 2022), and then the BGT data are used for manual inspection to meet the requirements of space syntax analysis. Population and neighbourhood data are obtained from CBS (Dutch Central Bureau of Statistics). The data for digital models and photographs used in 3D landscape analysis were collected during the fieldwork in August and September 2022.

As mentioned above, eight methods for measuring blue space quantity, accessibility, and visibility are introduced to explore their application potential in multi-scale design processes. Each technique has unique features, so the next section and the supplementary materials of Zhang et al. 2023b give extensive method descriptions, application outcomes, and interpretations of results from the design perspective.

4.4 Applications of Methods for Measuring Blue Space Quantity, Accessibility, and Visibility

Eight methods are applied at different scales to measure blue space quantity, accessibility, and visibility, addressing space from quantitative and qualitative perspectives and evaluating the study results from the design perspective.

4.4.1 Measuring Quantity, Accessibility, and Visibility at the Regional Level

Two neighbourhood units are selected for analysis in describing blue space quantity, accessibility, and visibility at the regional level: *Wijk* and *Buurt* (in Dutch). These measures were developed by the CBS based on the characteristics of urban history, development, and design, making them suitable for analysis at the regional level. Typically, Wijk is larger in scale and contains several Buurts that are dominated by a single primary function. Figure 4.4 [1–4] shows the spatial patterns of the blue quantity, accessibility, and visibility in Rotterdam, produced by the statistical index approach based on Wijk and Buurt, respectively. As previously discussed, the statistical index approach is primarily employed for quantifying blue spaces. However, its simplicity also makes it a widely utilised alternative indicator for assessing accessibility and visibility.

Here, the statistical index approach counts the total blue space area (supplementary materials of Zhang et al. 2023b), the percentage area of blue spaces over the total area ([1], [3]), and the per capita area ([2], [4]) of blue spaces within different Wijk or Buurt as indicators, with darker colours indicating higher blue space quantity, accessibility, and visibility. The results of the three indicators present a similar pattern: high-exposure areas (red areas) appear in the western part of the city, away from the city centre, and mainly serve as the port area. Within the city centre, the spatial distribution of high blue exposure areas is scattered, primarily appearing in the neighbourhoods located in the central and southern parts of the city.

TOC

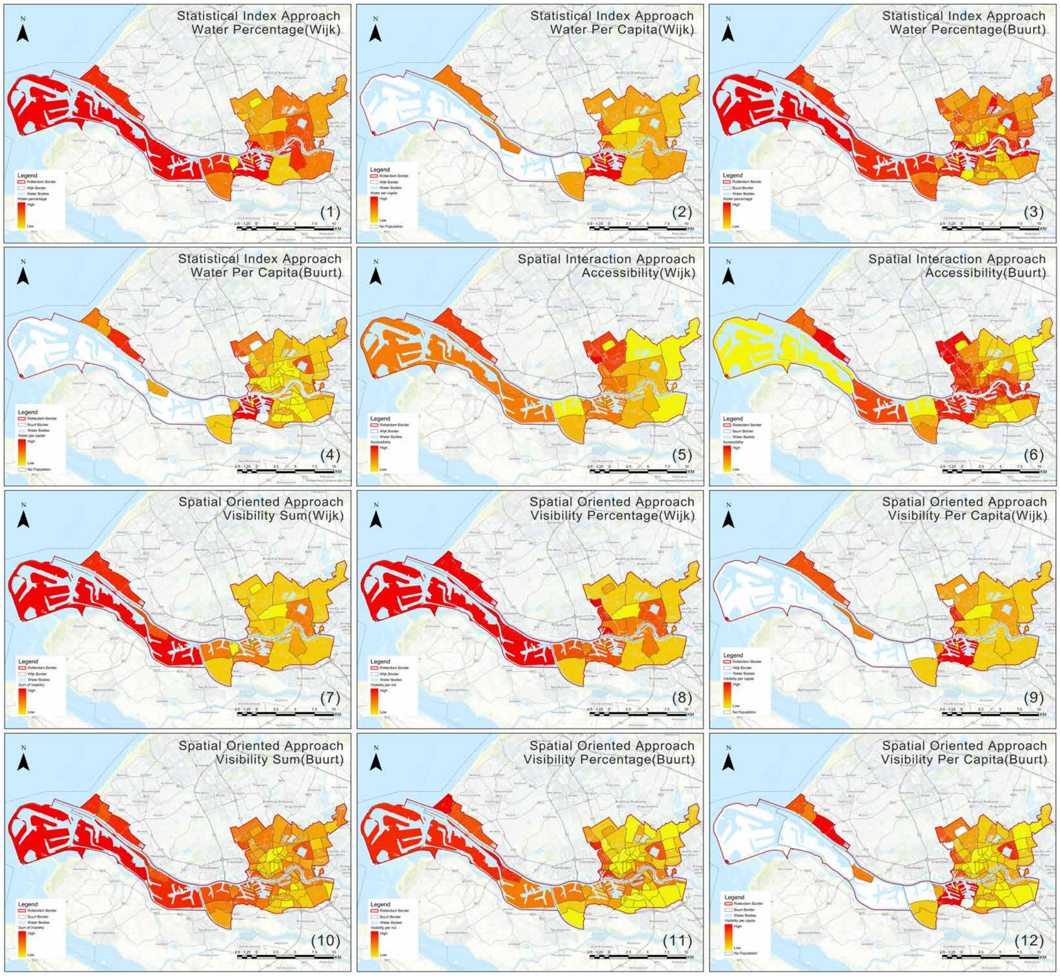


FIG. 4.4 Analysis at the Regional Level Based on Wijk and Buurt Boundaries.

Figure 4.4 [5–6] presents the results of the spatial interaction approach considering the supply-demand relationship between resources and the population. The results are also summarised based on Wijk and Buurt borders, where darker colours indicate better accessibility. The Gaussian-based two-step floating catchment area (G2SFCA) method is adopted in this research since its simplicity in implementation and data availability (Dai, 2011; Li et al., 2019; Wang, 2012). A detailed description of the G2SFCA method is presented in the supplementary materials of Zhang et al. 2023b. The average accessibility index of all population grids in Rotterdam was 121.33, indicating the great overall accessibility of blue spaces. According to the spatial distribution of areas with high accessibility, the Nieuwe Maas River is the most important provider of blue spaces.

On the other hand, the standard deviation of the accessibility index is 239.48, showing apparent spatial differentiation among population grids. From the mapping of the result based on the Wijk border, it can be found that the northeast and southeast neighbourhoods, including Prins Alexander and IJsselmonde, have relatively poor blue space accessibility. In addition, the smaller border (Buurt) mapping results indicate that the detailed areas with weak blue space accessibility are mainly located in the city's northeast, central, and southern neighbourhoods. However, some of these smaller neighbourhoods (Buurt) have good accessibility, while they are classified as areas with low accessibility in the larger neighbourhood (Wijk) border mapping, including Oude Noorden and Agniesebuurt.

The spatial-oriented approach is conducted to analyse blue visibility at the regional level through the cumulative viewshed analysis method. Its results are presented in Figure 4.4 [7–12] and also summarised based on the Wijk and Buurt borders. Cumulative viewshed analysis is widely used in research on the visual impact assessment (VIA) of specific projects (Palmer, 2022). This study extends its application to the visibility of bodies of water by setting the point matrix with multiple grids. Detailed descriptions of the analysis method and the sensitivity analysis for selection modelling grids are presented in the supplementary materials of Zhang et al. 2023b. In general, locations with strong blue visibility captured by the spatial-oriented method are found on both banks of the Nieuwe Maas River and near major lakes, demonstrating that large-scale bodies of water have a more significant impact on visibility. Additionally, dense high-rise buildings along the Nieuwe Maas River may impede visibility from distant neighbourhoods, except those in the west port region with low-density and low-height structures. Incorporating population data into cumulative blue visibility study results (Figure 4.4 [9] and [12]) demonstrates that city centre blue visibility declines, especially for the results on the Buurt border. When the total area of each neighbourhood is considered (Figure 4.4 [8] and [11]), the changes in overall patterns are limited, while the visibility of some neighbourhoods is amplified.

Comparing the three approaches' spatial patterns reveals multiple similarities and some variations. In general, existing studies have shown that the spatial interaction approach – including the supply-demand relationship and the spatial-oriented approach – describing cumulative blue visibility provides more accurate results than the statistical index approach (McDougall et al., 2020; Wang et al., 2021). These analyses can provide the basis and evidence for spatial planning and design at the regional level in four aspects. First, identifying the areas with high and low blue exposure could support proposing regional spatial development strategies and policies, such as increasing blue space provision in low-exposure areas, enhancing the development of high-exposure areas, controlling building height, or reserving visual corridors to increase blue visibility from distant areas. Second, different types of blue spaces can significantly influence blue exposure, whereby linear bodies of water significantly affect blue accessibility, and large-scale bodies of water greatly impact blue visibility. Therefore, Rotterdam's overall blue space accessibility and visibility could be improved by adjusting the regional traffic structure or visual corridors related to linear and large bodies of water. Thirdly, the findings from the regional-level analysis, utilising various neighbourhood boundaries (Buurt and Wijk), can inform and support more targeted spatial interventions at the district/local level. This approach enhances the relevance of spatial strategies by addressing discrepancies in classification; for instance, neighbourhoods (Buurt) that actually have better blue space accessibility and visibility might be categorised as having lesser accessibility and visibility when evaluated within the broader context of larger-scale neighbourhood boundaries (Wijk). Lastly, considering the results of the accessibility and visibility analysis together can lead to targeted recommendations. For instance, in Noord Wijk, where accessibility is good but visibility is limited, design strategies should specifically focus on enhancing blue space visibility. On the other hand, the identification of areas with poor blue quantity, accessibility, and visibility can provide support for policymaking. For example, Oude Noorden, Agniesebuurt, and Provenierswijk Buurt in Noord Wijk could be considered critical for subsequent spatial interventions as they have relatively low values in all three methods.

4.4.2 Measuring Accessibility and Visibility at the District Level

The spatial proximity and object-based approaches are applied to describe the blue accessibility and visibility at the district level. As mentioned above, the minimum costs for visiting blue spaces are selected as the indicators to describe blue accessibility at this level. Existing studies suggest multiple means to measure such travel costs. Euclidean distance between individual locations and blue spaces could be the most commonly used way to measure travel distance, which is convenient to conduct in GIS. However, the simplicity of Euclidean distance calculation leads to inaccuracies. It is widely recognised that network-based analysis could provide more accurate measures of travel costs to capture actual travel behaviour (Wang et al., 2021).

On the other hand, the network-based analysis method primarily relies on the modelling quality of the road network, which poses challenges to data availability. With advanced technology and novel geo-big data approaches, the API function of the online map platform could provide a promising measurement of space-time accessibility by estimating travel time costs (Rothfeld et al., 2019). Compared to the Euclidean/network-based analysis, its advantages are three-fold: (1) the higher precision of the results on space-time accessibility by considering the combination of real-time traffic flow and door-to-door distance; (2) describing individual movements and reflecting behavioural preferences directly through estimating travel time costs; (3) no need for advance preparation with updated road network data available.

Inspired by Rothfeld et al.'s (2019) research, the travel time and distance between blue space entrances and individual locations are obtained from the Google Maps Distance Matrix API. Several neighbourhoods (Buurt) located in the city centre are selected as case studies (Figure 4.3). These neighbourhoods encompass various blue spaces and exhibit a population density that exceeds the city average. Collectively, the selected area covers an approximate area of 9 km^2, corresponding to the district level in our study. Subsequently, the walking travel time mapping is generated with the resolution of 50*50m through the assistance of the Distance Matrix API and QGIS. Next, the number of blue space entrances that can be reached is mapped according to different time thresholds, including 5, 10, and 15 minutes. The selection procedures of the blue space entrances, the application of Distance Matrix API, and the mapping processes are explained in the supplementary materials of Zhang et al. 2023b.

Figure 4.5 shows the results of the spatial proximity approach analysis. In general, areas with high accessibility – captured by travel time – are located in the southern part of the study region with denser coverage of road networks. The less accessible areas exist mainly in a small part in the north and northeast, as the adjacent highway blocks the walking routes. Only a few areas can reach multiple blue space entrances within five minutes of walking. As the time threshold increases, more blue space entrances are accessible. However, areas in the north and northeast and some scattered areas still retain poor accessibility, where even the number of blue space entrances reachable within 15 min walking is limited. The measurements and visualisations of travel costs or related indicators calculated by the spatial proximity approach allow designers to better identify areas that require design interventions and are closely related to spatial design projects at the district level. In addition, the different indicators calculated by the spatial proximity approach can provide mutual support for identifying areas with limited accessibility.

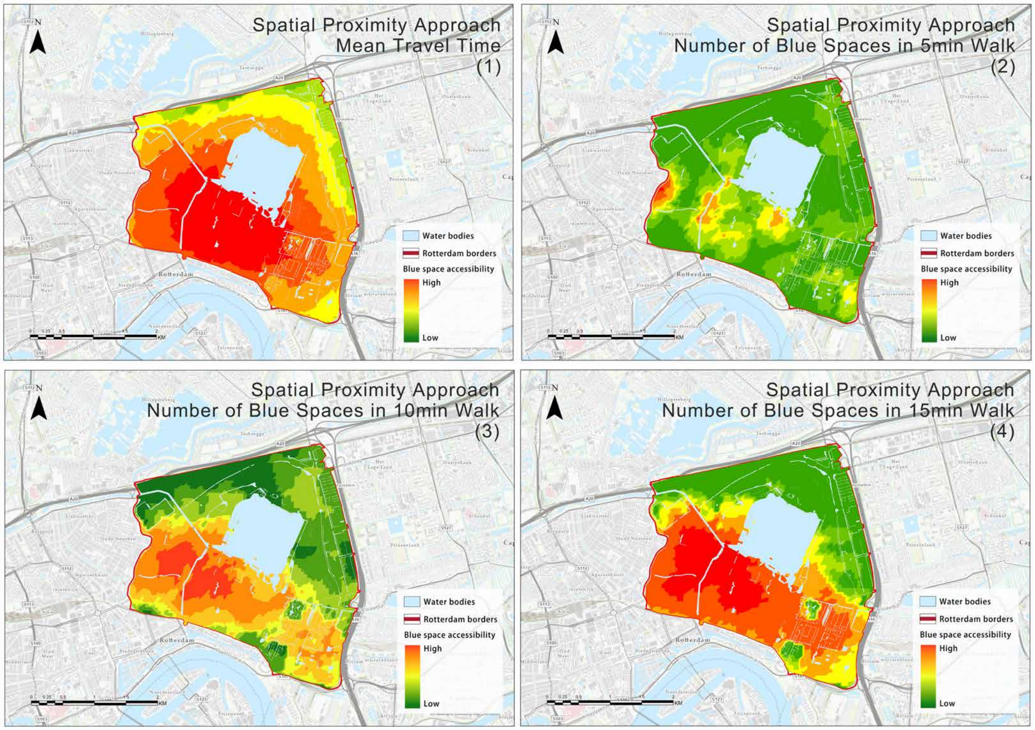


FIG. 4.5 Accessibility Results at the District Level.

While describing accessibility via travel costs of movement, the object-based approach analyses the visibility of blue spaces at the district level, emphasising the blue visibility during movements and requiring a more precise representation of physical environments. Viewshed analysis used in the spatial-oriented approach could also be adapted to measure blue visibility in this situation to some extent. However, it is mainly conducted in GIS environments relying heavily on 2.5D geometry, and the accuracy of modelling physical environments may not be guaranteed (Ruzickova et al., 2021). Therefore, a novel method called the object-based approach, is developed in this chapter to describe visibility at the district level. Relying on the Isovist analysis, it is conducted in the Rhino-Grasshopper environment by considering transportation modes, directions, and characteristics of viewing during movements, providing interactive results directly (Figure 4.6). Compared with viewshed analysis, it introduces 3D geometry for analysis, which dramatically improves the accuracy of modelling and calculation. On the other hand, the object-based approach presents the advantage of usability and real-time interactivity, allowing practitioners to quickly understand the blue space visibility under movements and simulate various scenarios to support decision-making, even though the precision may be lower than the segmentation analysis using in-site photos.

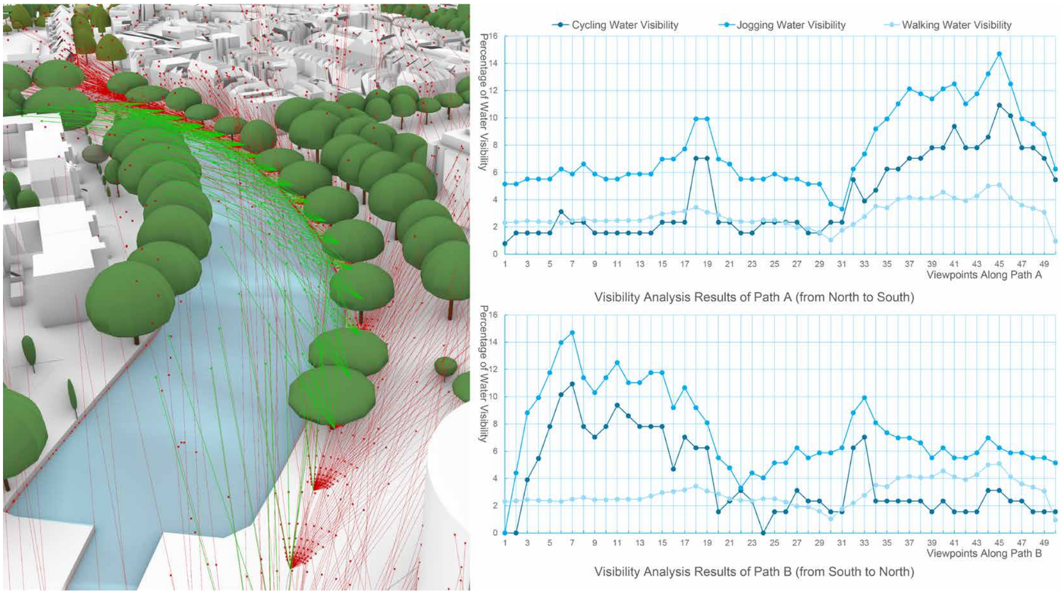


FIG. 4.6 Object-based Approach in Rhino-Grasshopper Environment, with Results on the Blue Visibility of Two Paths Based on Three Transportation Modes.

Figure 4.6 shows the analysis of two directions and three transportation modes, which can directly identify the changes in the blue-visible range in movements. The blue visibility results of the two directions reveal a similar pattern. The northern section of the selected route shows lower visibility of blue spaces compared to the southern section, which has relatively higher blue visibility. The differences within the route could be that the northern section has more vegetation, leading to less visible blue spaces. In addition, blue visibility while jogging alongside the route is the highest among transportation modes in both directions, while blue visibility is the lowest during walking. There are inconsistencies in the blue visibility of the three transportation modes, which vary significantly in blue visibility change but show a similar trend for jogging and cycling.

In contrast, the blue visibility of walking has a unique trend with limited fluctuations. This difference may be caused by the variations in the field of view (FOV) among different traffic modes. More explicitly, walking has a wide FOV, while the FOV of jogging and cycling mainly concentrates forward to avoid dangers ahead. On the other hand, some sections with abnormally high or low blue visibility can be identified, such as viewpoints 1, 2, and 24, showing the lowest blue visibility while cycling along path B, significant blue visibility changes happening at viewpoints 18–19 while cycling and jogging along path A, and a similar pattern in viewpoints 32–33 along path B.

The above results of the object-based approach could be used to assist spatial design in multiple ways. First, this analysis can support vegetation planning and design by comparing the differences in blue visibility caused by vegetation locations through simulations. Second, the analysis of different transportation modes can support route planning and design. The above results are partially similar across three transportation modes, as there is no clear lane classification or design among different transportation modes. Lastly, the detailed analysis of specific route sections can help designers better implement and test their design intentions, such as the lower blue visibility of cycling routes at intersections to prevent distraction.

4.4.3 Measuring Accessibility and Visibility at the Local Level

Blue accessibility and visibility at the local level mainly concern people's direct perception without movements. As mentioned above, 3D landscape analysis could qualitatively describe both accessibility and visibility. Moreover, the spatial configurational approach can be employed to quantify accessibility, whereas the object-based approach and segmentation analysis are suitable for measuring visibility. Derived from visual landscape research, 3D landscape analysis envisions landscape spaces from the user's perspective through 3D visualisations. Critical techniques for 3D landscape analysis are sketches, photographs, photomontages, and some emerging digital or virtual tools, including digital modelling and virtual reality interactions. They can provide comprehensive insights about several static landscapes and reveal dynamic landscape changes via serial analysis, especially when describing blue visibility (Cullen, 2012). To keep the method simple and designer-friendly, 3D models and site photographs are used to illustrate the application of 3D landscape analysis in this research.

Figure 4.7 presents the 3D digital models of typical water edges alongside the Rotte River in Rotterdam. Accessibility at the local level is understood as the difficulty of physically contacting the bodies of water, which can be qualitatively and directly perceived by designers from 3D models. The digital models of Rotte River's edge can be divided into five groups, ranging from high to low accessibility. More specifically, the water edges with the highest accessibility mean they provide extensive on-water facilities, allowing people to interact with the body of water easily. Conversely, the water edges with the lowest accessibility hinder access, as shown in the last column of the models, where car parks impede the path to the water. The accessibility of the three middle groups in descending order refers to the provision of limited on-water facilities, the provision of on-land facilities for interacting with the body of water, and the provision of on-land open spaces adjacent to water. Due to the method's subjectivity, the benchmark for evaluating accessibility can vary between projects and contexts.

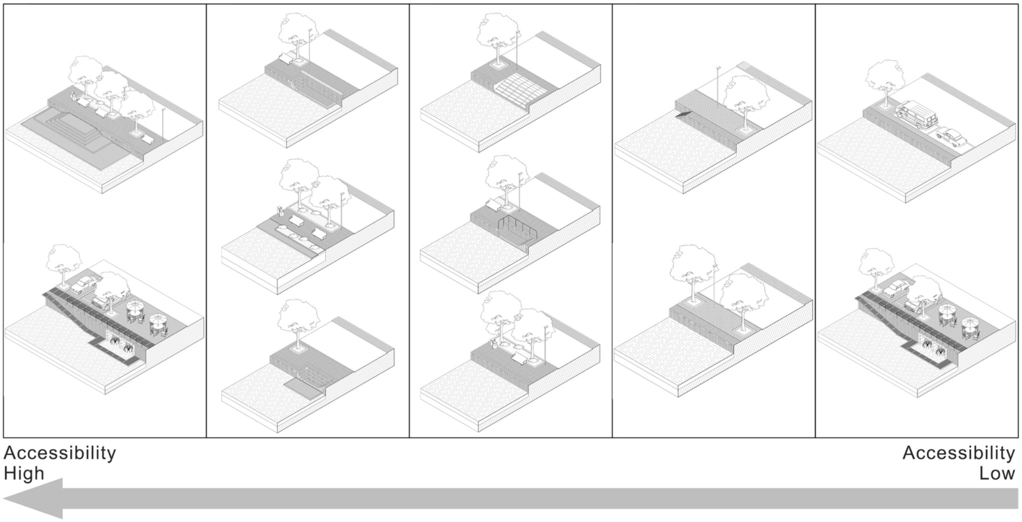


FIG. 4.7 3D Models of Different Water Edges in the Rotte River.

3D landscape analysis has widely been adopted to grasp spatial-visual attributes, including visibility (Cullen, 2012; Liu & Nijhuis, 2020). For instance, a set of photographs alongside the Rotte River in Figure 4.8 demonstrates the differences in blue visibility along the walking route. Figure 4.8 [1–3] shows how the facilities (on-water buildings, car parks, and facilities) may interfere with the public's view of the water while walking and reduce the quality of the blue view, even when the body of water occupies a large proportion of the view. Figure 4.8 [4–6], where water also occupies a significant sector, shows that the public has better blue visibility when walking. The blue area of Figure 4.8 [5–6] shows that some facilities could enhance the quality of blue visibility. The fountains and colourful vegetation in a different direction from the movement may attract more visual attention and cause the observers to stop and enjoy the view.

On the other hand, the platforms in Figure 4.8 [6], consistent with movement direction, could also attract visual attention and serve as the activity destination. 3D landscape analysis thus helps the designer quickly implement and extract subjective connotations from their results, which can help design decisions in practice. However, relying too much on the designer's judgement could lead to difficulties, limiting the result's re-use elsewhere.

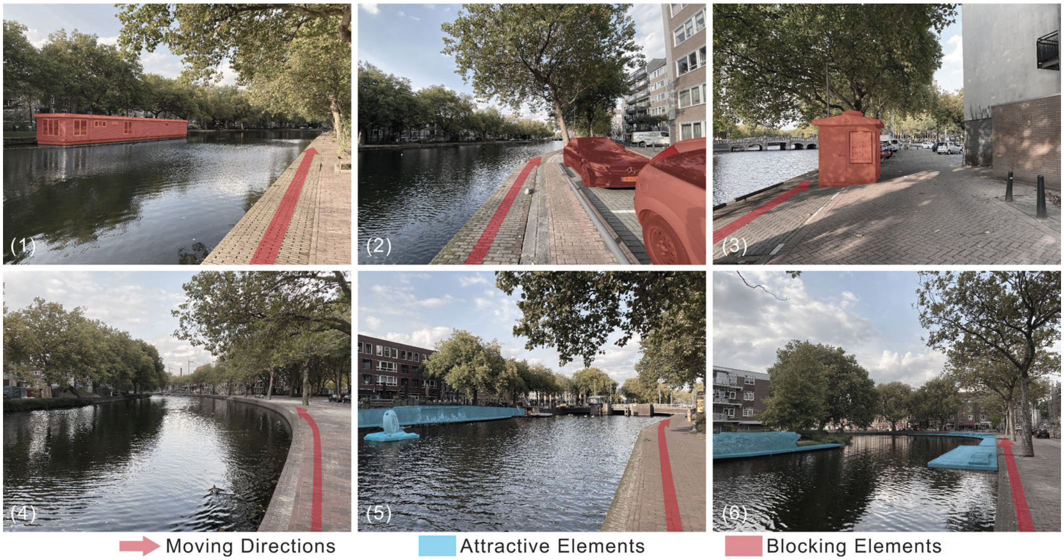


FIG. 4.8 Blue Visibility Analysis and Illustrations of a Set of Rotte River Photographs.

Unlike 3D landscape analysis, which emphasises the subjective understanding of accessibility, the spatial configurational approach explores specific 3D spatial characteristics and human behaviour patterns to describe accessibility quantitatively. Specifically, this study uses space syntax for analysis, which is the most widely used representative of spatial configuration approaches. Space syntax began as an exploration of the interaction between space layout and human mobility in a single building and expanded to urban contexts. This study adopts the latest angular model of space syntax for calculations, and the most representative indicators, including integration and choice, are used to describe the possibility of people reaching the destinations and the potential of moving through linear spaces, respectively (Turner, 2007; Yamu et al., 2021).

Figure 4.9 presents the partial results of the spatial configurational approach by using space syntax. To comprehensively understand the result and improve its reliability, several distance thresholds representing different travel durations are included in the analysis (full results are presented in the supplementary materials of Zhang et al. 2023b). The results show similar spatial patterns across different distance thresholds: the roads with higher integration or choice value are located in the very centre of the city. Meanwhile, the main road networks with critical higher values are identified as the threshold increases. According to the detailed observation of the integration value, Kralingen Lake may not be an accessible destination for people to visit from a spatial configurational perspective due to the low integration value of its surrounding roads. At the same time, it makes significant contributions to blue visibility at the regional level. Some linear blue spaces along higher choice routes are noted in Figure 4.9 [4–6], suggesting that they are more likely to be used in people's everyday lives, including the Rotte River, Westersingel, and the middle portion of the Boezem River. For practitioners, the spatial configuration approach could provide insights into multiple characteristics of accessibility at different scales. Specifically, the results can identify areas with poor overall road accessibility and evidence for design interventions on traffic structures at the regional/district level. Moreover, through extensive interpretations of the analysis, the effects of the surrounding spatial layout of the targeted blue spaces on accessibility may be revealed, allowing for spatial interventions at the local level.

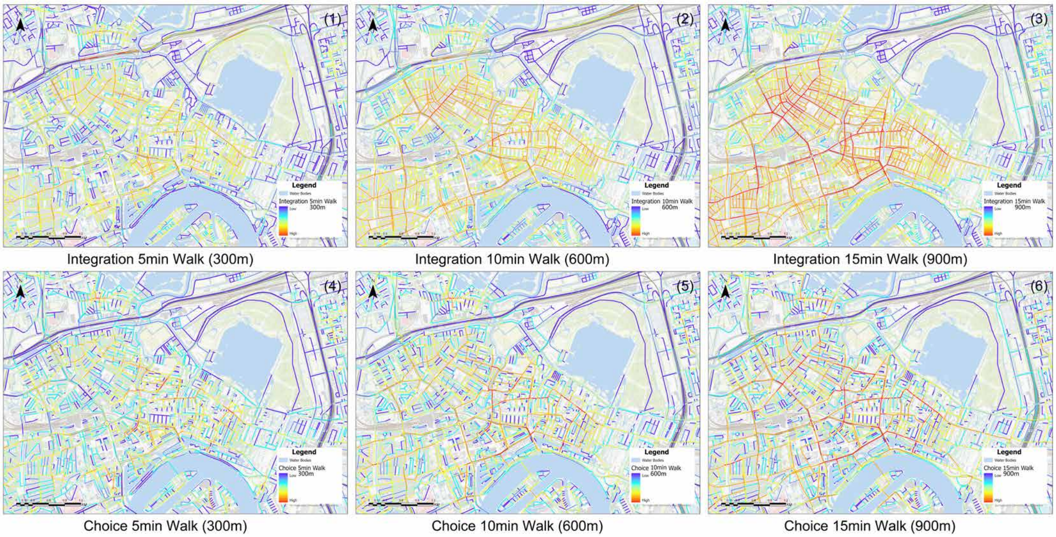


FIG. 4.9 Results of the Spatial Configurational Approach Using Space Syntax.

An object-based approach could not only be adopted for analysing visibility at the district level but also could support the measurement of visibility at the local level. Compared to the measurement of blue space visibility at the district level, the object-based approach at the local level primarily focuses on specific locations as the analysis objects, calculating the visible proportion of blue space from those points. As previously noted, this method offers the advantage of real-time interactivity, enabling designers to explore multiple scenarios. In this chapter, several buildings along the Rutte River in Rotterdam are examined to illustrate their potential.

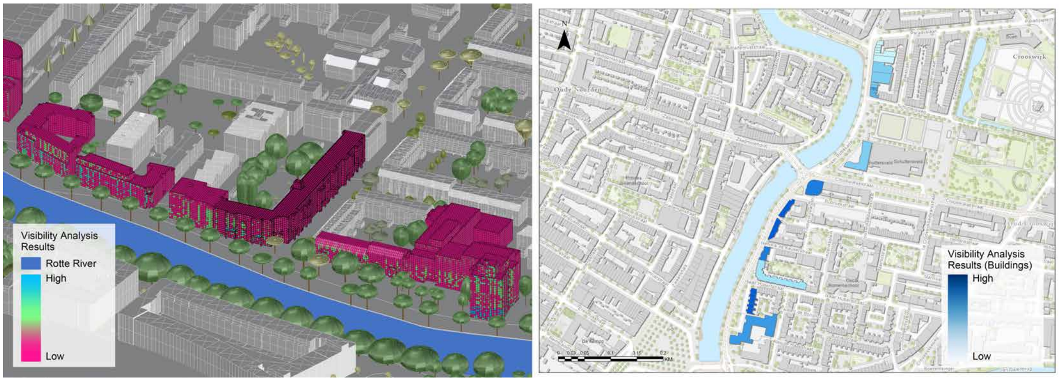


FIG. 4.10 Left: Visualise Blue Visibility Analysis Results on Building Surfaces; Right: Summarise Analysis Results on Map.

Figure 4.10 presents the results directly on building surfaces, where the surfaces shaded in blue indicate a higher level of blue visibility. In comparison, the surface shaded in red 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 demonstrates that a hospital ward with a natural view could have a positive influence on the recovery of the patients staying there. The result can assist designers in architecture or vegetation design, adjusting the layout of buildings or vegetation and repositioning the windows or vegetation to increase blue visibility. On the other hand, the results of the analysis could provide evidence for planning and policymaking at an intermediate scale. Specifically, the study calculates the average blue visibility of each building surface cell and visualises 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 (Figure 4.10). This research merely uses a few riverside buildings for testing. In the future, the analysis could be extended to the buildings within a specific area to support the planning of entire neighbourhoods.

Segmentation analysis is a machine learning–based visibility analysis method that corresponds to the local level and is widely used to understand the spatial characteristics of landscape elements within fixed scenes or images. It provides accurate encoding and decoding for multi-class scenes and conducts the composition analysis by identifying different landscape elements with colours. Following the analysis 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. More than 210 images from the on-site research are used as input images for segmentation. The number of elements in each scene and the ratio of different elements to total pixels are calculated as indicators of blue visibility.

FIG. 4.11 The Segmentation Samples of Typical Photos of the Rotte River.

Figure 4.11 shows examples of segmentation analysis on typical scenes alongside a section of the Rotte River where areas of different colours represent various landscape elements. These graphs directly visualise the component analysis, which designers could adopt to compare the differences of landscape elements in specific scenes pre-/post-design interventions. On the other hand, Figure 4.12 shows the number of elements in the scene using the segmentation results. The number of elements in current scenes is concentrated between 20 and 35, and the number of elements where the FOV accounts for more than 5% and 10% are concentrated in 3–7 and under 5, respectively. Designers can use this method to measure spatial-visual complexity in selected routes and areas, which has been widely adopted in several studies (Ode et al., 2010). Existing studies reveal that people prefer moderately complex coherent environments, and scenes with relatively high complexity are more likely to stimulate people's interest in exploration (Forsythe et al., 2011; Nadal et al., 2010).

To clarify the approach's potential for understanding the characteristics of typical scenes, this study divides the river into three sections to compare their differences (Figure 4.2). Based on the results regarding the number of elements among the three sections (Figure 4.12), Section 3 is higher than the other two sections, showing that it has relatively high visual complexity. Section 1 is more concentrated and possess fewer large values, demonstrating that its visual complexity is stable and relatively easy to understand. However, Section 2 presents more scattered patterns than the others, indicating that people's visual perception changes in this section are more significant. Furthermore, the results can be used to calculate the degree of openness and naturalness of scenes, two critical indicators designers use to describe the visual space, while traditional methods rely heavily on photo-based qualitative descriptions.

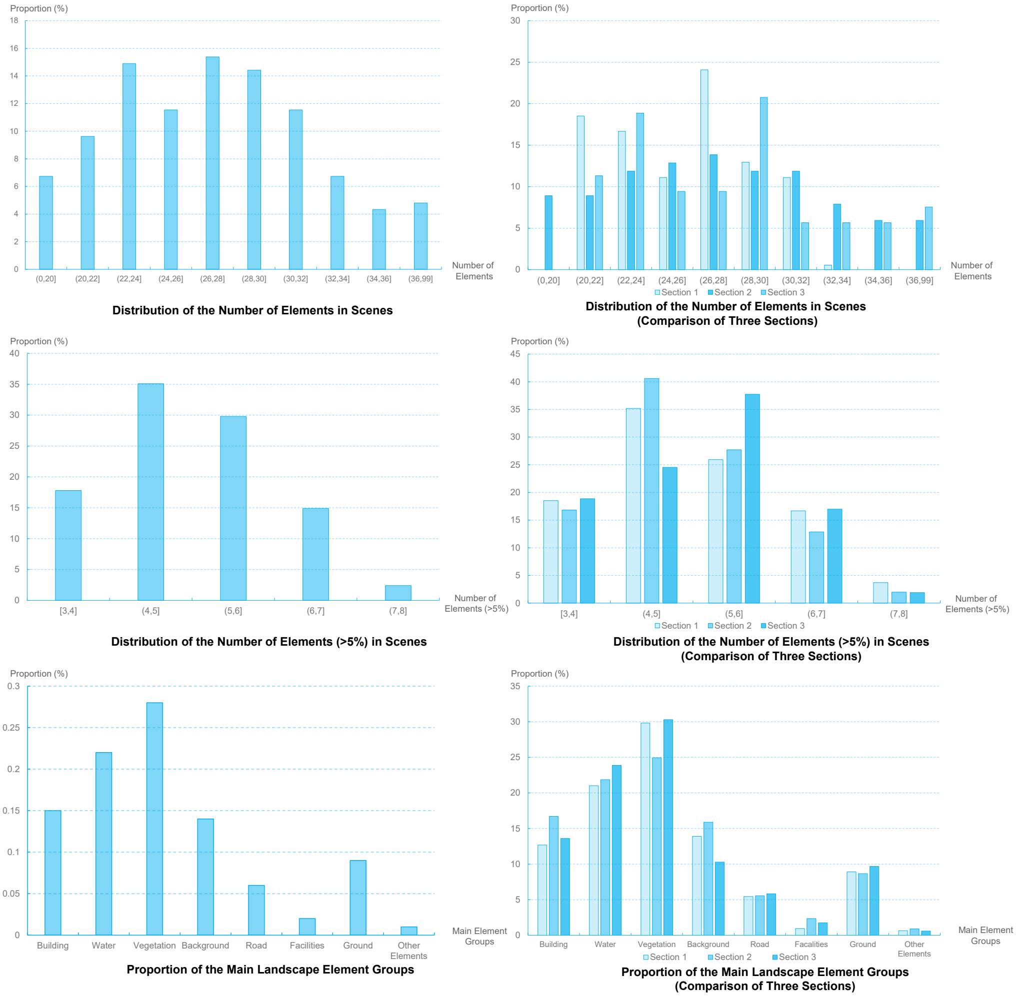


FIG. 4.12 The Statistical Analysis (Based on the Segmentation Analysis).

The average proportion of area occupied by the main landscape element groups is shown in Figure 4.12. Detailed information on group re-classification is presented in the supplementary materials of Zhang et al. 2023b. The result reveals that vegetation, water, and sky are the main landscape element groups in scenes, while multi-facilities (on-water, on-land, and traffic facilities) only occupy a limited proportion. Among the results of the three sections, it is evident that the proportion of vegetation in scenes of Section 2 is lower than in the other two sections, with a higher proportion of buildings. More buildings could also illustrate that the visual perception of this section is dynamic and varied. Thus, based on the above results, designers can use segmentation analysis to analyse and simulate different design intentions by incorporating photomontages or digital modelling.

TOC

4.5 Discussion

4.5.1 Choosing the Appropriate Methods for Measuring Quantity, Accessibility, and Visibility

The analysis of the eight methods' applications in multi-scale Rotterdam cases demonstrates that different methods produce distinct types of design theme descriptions that may be suitable in various contexts. Therefore, it is necessary to identify and select appropriate methods when encountering spatial planning or design assignments aiming to improve blue space quantity, accessibility, and visibility. As mentioned above, the eight methods are first classified according to the three design themes (i.e. quantity, accessibility, and visibility), which should correspond to the design intentions of spatial interventions. For instance, the spatial proximity approach focuses on proposing spatial interventions to reduce travel costs, while the object-based approach emphasises visual exposure during movement.

On the other hand, the scale applicability of the various methods (i.e. regional, district, and local levels) indicates a particular input data type and precision. Therefore, data availability and situations for method applications become critical factors in designers' method selection. For example, the statistical index approach is easy to calculate and applies more readily to uniformed spatial units, which provides the potential for rapid analysis and communication (Wang et al., 2021; Zhang et al., 2011). However, spatial interaction and spatial-oriented approaches with rich data input could better represent blue space accessibility and visibility and provide solid evidence for design decisions than implementing statistical index approaches.

Instead, the scale can offer clues that help designers select suitable methods in practice and explore the possibilities of collaborative analysis via crossing-scale methods. For instance, the methods at the regional level could identify the areas with limited blue space accessibility or visibility, which could inform specific spatial design interventions at the district/local levels. More broadly, the results across various design themes can complement one another and facilitate the formulation of specific spatial interventions. For the areas with inconsistent results regarding quantity, accessibility, and visibility, designers can propose targeted strategies that combine the considerations of their contexts rather than over-emphasising one aspect without supporting evidence. Moreover, multiple indicators in the analysis of the same design theme could support designers in identifying site limitations and proposing targeted interventions, as the results of the spatial proximity approach demonstrated in Section 4.4.2.

Lastly, as shown in the last column of Table 4.1, the different interactions between methods and spatial design processes play critical roles in method selection and application. Two groups of methods are pointed out, including pre/post-planning or design analysis methods and scenario-based analysis methods. Specifically, the two groups all emphasise the nature of evaluation and analysis, allowing designers to compare the differences between multiple prospective design proposals and the original situations to make decisions. However, compared to pre/post-planning or design analysis methods, scenario-based analysis methods pay more attention to the characteristics of rapid simulations, which allow designers to test and change the ideas or intentions quickly through visualisations and often link to projects at the district/local level.

4.5.2 Potential Applications

Spatial planning or design, a fundamental activity in urban design and related disciplines, encompasses creativity, rationality, and interdisciplinary collaboration (Nijhuis & de Vries, 2019). The methods shown in this study enable designers to understand and visualise blue space exposure at multi-scales and explore the potential for improving it. The results section presents potential applications of these methods in spatial planning/design processes, highlighting their relevance to practitioners. Beyond their integration into planning processes, these methods hold valuable implications for urban planning and public health policies. This section will concisely summarise these possibilities and propose a conceptual flowchart for integrating these multi-scale methods into the spatial planning/design and policymaking processes, recognising the interconnectedness of spatial projects and interventions across different scales.

4.5.2.1 Spatial Planning and Policymaking Processes

The statistical index approach primarily quantifies the amount of blue space by measuring the quantitative characteristics of blue spaces within specific geographic areas. In situations where there are constraints on time and data availability, this approach can also serve to measure accessibility and visibility. However, the spatial interaction and spatial-oriented approaches directly represent accessibility and visibility, providing insights that are not attainable through the statistical index approach. These three methods demonstrate the spatial distribution and inter-regional relationships of blue spaces, enabling designers to propose regional spatial strategies and visions of the future that maximise the health benefits of blue space. In addition, these methods have the potential to be combined with additional contextual data for analysing the spatial distribution inequities of blue space, thereby supporting more comprehensive policy development.

The spatial proximity approach can precisely visualise the accessibility of blue spaces within neighbourhoods, which allows for the immediate identification of areas with inadequate access to support developing targeted spatial strategies. The object-based approach captures the variations of blue space within the FOV during movement, making it useful for site analysis and simulating the impacts of different design proposals. Furthermore, specific spatial strategies and proposals derived from these approaches can be integrated into policies to guide future urban development.

At the local level, 3D landscape analysis is easily generated through field surveys to understand the site situations with limited data availability. Real-time sketches, photographs, and digital modelling are practical tools in 3D landscape analysis, allowing designers to explore the relationship between characteristics of spatial forms and blue space accessibility or visibility. On the other hand, the spatial configuration approach, object-based approach, and segmentation analysis enable designers to quantitatively describe blue space accessibility and visibility, providing more solid and objective evidence for design decisions. All three methods could be applied in the analysis and evaluation phases to allow multiple stakeholders to communicate regarding potential design proposals, resulting in a dynamic and interactive design process. Additionally, these methods could serve as a platform for policymakers to engage with stakeholders and the public, facilitating the identification of trade-offs and synergies among various factors and enabling the proposal of more inclusive policies. For instance, the findings from the spatial configurational approach highlight the importance of spatial morphological features, which could be influenced by factors such as road networks and building layouts. Addressing these considerations necessitates collaborative policymaking efforts.

Notably, the methods at the three scales are independent but closely connected to the results of the methods at other levels. Figure 4.13 illustrates the method application in spatial planning/design and policymaking processes with a simplified conceptual flowchart to facilitate understanding among practitioners, as the analysis–application–evaluation loop may require several rounds to make design decisions. Specifically, regional-level methods could first be used to understand the limitations of existing situations and provide evidence to support spatial interventions in regional planning/design projects. Next, these methods could also be adopted to evaluate the consequences of different interventions to help

TOC

designers communicate and make final decisions, as the complexity of urban issues defies a one-size-fits-all solution. In addition, the results of current situations could inform the design of future spatial interventions. For instance, areas with limited accessibility identified using regional-level methods may serve as potential input sources for projects at the district/local level (Figure 4.13). Second, the results obtained from these methods can be used as a powerful communication tool among stakeholders, facilitating the identification of trade-offs and synergies between spatial visions. This kind of communication enables the development of diverse policies for healthy urban environments, spanning urban planning, public health, and urban design. Furthermore, the strategies for enhancing blue space exposure derived from spatial planning and design, informed by these methodologies, can help develop and refine public policies.

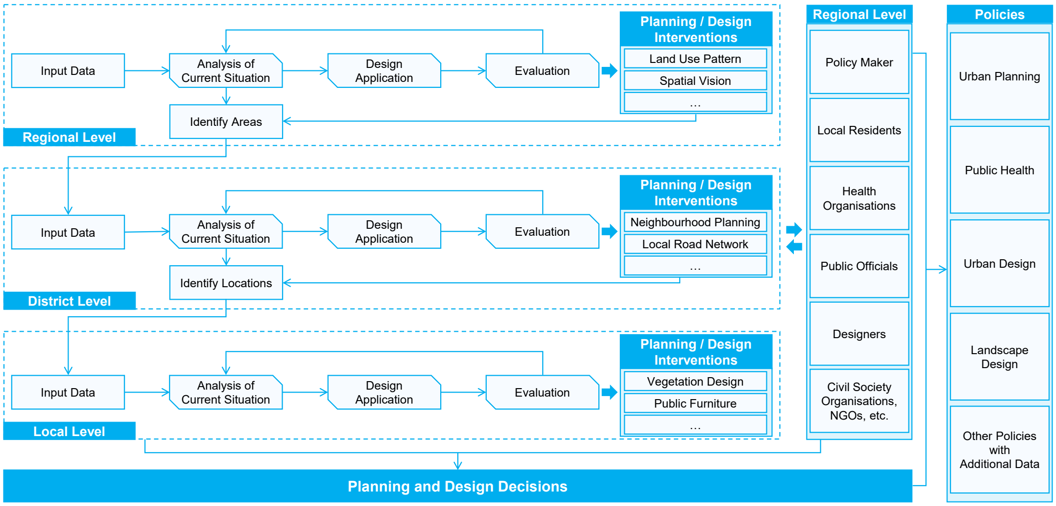


FIG. 4.13 A Conceptual Flowchart for Incorporating Multi-scale Methods in the Spatial Planning/Design and Policymaking Processes.

TOC

4.5.2.2 Policy Implications

Integrating methods to analyse blue exposure in urban planning is paramount for promoting public health and well-being. Accordingly, policymakers, urban designers, and landscape architects could forge collaborative partnerships to streamline these methods into planning processes. For instance, improving access to and enhancing the visibility of blue spaces within urban contexts can be a shared objective, necessitating the city's proactive evaluation of the accessibility of these spaces. Following these analyses, policy interventions could encompass devising pedestrian-friendly routes to nearby bodies of water and augmenting public transportation options for more distant blue spaces. Simultaneously, strategic measures can be undertaken to enhance the visibility of blue spaces, such as issuing guidelines for developers to use when integrating blue spaces into city-wide strategic plans or when redesigning built environments to expand sightlines towards bodies of water and create view corridors.

Achieving equitable blue space accessibility and visibility across various regions and for diverse population groups is critical, especially when considering qualitative factors. As such, policies should advocate for the comprehensive evaluation of blue spaces' regional distribution, providing a foundation for devising spatial strategies and future visions for equitable blue exposure (Song et al., 2021). Moreover, policies could extend beyond mere quantification of the three themes to encompass the quality, functionality, and usage of these spaces, which may include regulations or guidelines for maintaining and improving urban blue spaces (Knight et al., 2022). In the case of Rotterdam, a concentrated effort to examine the regional distribution of blue spaces could be made to offer equitable access to all residents, irrespective of their geographic location within the city. Furthermore, it is vital to acknowledge the crucial role of data availability in effectively implementing these methods. Thus, there is a need to advocate for open data policies to ensure the method is applicable to constructing healthy urban environments.

4.5.3 Limitations

The summary of evidence in Part I suggests that enhancing the quantity, accessibility, and visibility of blue spaces can effectively facilitate access to their health benefits. Therefore, considering these three themes in spatial design is crucial in constructing healthy urban environments. To comprehensively understand and measure the quantity, accessibility, and visibility of blue spaces in practice, the available methods and tools addressing the three themes from a spatial standpoint are of fundamental importance for multi-scale spatial design and supporting practitioners' decisions. As highlighted in the previous chapter, these methods could be regarded as the critical components of practical knowledge for designers and planners. However, several factors are not included in this chapter, such as those related to spatial quality. The methods presented in this chapter mainly support practitioners in analysing the quantity, accessibility, and visibility of blue spaces and partially consider visual quality. Future studies could encourage the use of more methods or tools to aid design decisions and policymaking by considering the remaining factors with site-based analysis (Chapter 6).

The focus of this chapter on one city may raise concerns about the inadequate applicability of the method in other areas, such as water-scarce areas. Despite the issue of replicability, the reason for selecting Rotterdam lies in the abundance and diversity of bodies of water within urban environments, which allows the study to present relatively complex situations to promote applicability in other areas. Moreover, the study does not provide benchmarks as criteria to assess the indicators since the existing situations vary among different areas. The presented methods are designed to assist designers and policymakers in understanding the situation and supporting decision-making through simulations of different scenarios. However, the potential difficulties of applying these methods to other locales may not be fully identified without on-site tests. Therefore, future studies or practices could actively extend and apply the method to other areas to maximise their potential, as well as develop benchmarks as evidence accumulates to support decision-making.

On the other hand, the methods presented in the chapter have limitations in their selection, data processing, and analysis. First, due to the advancement of technology and the availability of methods or data, this study cannot include all potential methods in each theme but only applies those that could be incorporated into the design process efficiently. Second, the quality and precision of data adopted in the study could impact the results. For instance, visibility analysis through the Rhino-Grasshopper environment can partially address the limitations of the digital terrain model (DTM) in the GIS environment. However, the current data quality is insufficient to solve the issue of vegetation modelling fully. In this respect, the 3D point cloud provides promising clues to achieve more accurate results, while the high processing capacity requirement still makes it challenging to apply in practice. Finally, some new algorithms were not included in this research (such as deep-learning models for segmentation and distance decay models for 2SFCA), as the study aims to illustrate each method's current usability for designers and potential for design processes. However, new algorithms could provide the basis for future research and allow designers to explore their design applications.

4.6 Conclusion

This chapter provided an overview of practical methods for measuring blue space quantity, accessibility, and visibility, as well as their applications in Rotterdam, and then explored their potential in spatial planning/design and policymaking processes. These methods show great possibilities for becoming part of the toolset of urban designers, landscape architects, and policymakers and offer a new horizon to interpret quantity, accessibility, and visibility of blue spaces. Nevertheless, most of these methods come from interdisciplinary fields rather than directly from planning/design-related disciplines. Thus, they need to be combined when dealing with practical planning/design assignments due to the complexity of urban issues. In other words, each method has its own strengths and weaknesses, and using them in combination can effectively address the multi-scale issues of spatial planning/design. In general, the summary and applications of the methods contribute specific clues for future research and applications from the following three aspects:

- Expanding the understanding of blue space quantity, accessibility, and visibility from the spatial planning/design perspective. Existing studies mainly explore the relationships between blue space exposure and behavioural and health effects, while investigations of how to apply the evidence in the design process are limited (H. Zhang et al., 2022). The methods in this chapter can help designers apply such health evidence, gain insights into multi-scale spatial elements influencing the three themes, and implement interventions in design practice, which contribute to building healthy urban environments.

- Supplementing the body of design knowledge and the designer's toolset. The study showcases several methods that address the blue space exposure from multi-scales and provides a wide range of possibilities for exploring integrating these methods into spatial design in combination with case applications. In addition, these methods are applicable to other practical projects and studies with different geographic contexts, features, and data availability. Some of the methods can be extended to describe the quantity, accessibility, and visibility of other objects, including green spaces and critical public facilities.

- Exploring new perspectives for practice. As mentioned above, the methods presented in this study are mainly derived from various disciplines. Their multidisciplinary nature allows for knowledge exchange and reveals the innovative application of knowledge from different disciplines in planning/design and policymaking processes.

Future studies could expand the available methods by incorporating more interdisciplinary knowledge and emerging techniques while considering the convenience of practitioners' usage. At the same time, it is necessary to encourage the use of existing methods in practical cases to verify their effectiveness and explore their potential. Future empirical studies could employ current methods to standardise measurements of blue space, which could help infer blue health causality and provide more detailed support for a given policy. Last but not least, the logic of integrating emerging techniques into spatial design processes demonstrated in this study can be generalised to achieve broader objectives for the development of knowledge/evidence-based design approaches.

5 Design Principles and Spatial Patterns for Spatial Accessibility, Visibility, and Quantity

This chapter concentrates on developing design principles and spatial patterns within these three categories (the design knowledge relevant to spatial quality is presented in Chapter 6), aiming to integrate health evidence with best practices to help practitioners achieve the best possible spatial solutions across various scales. In particular, Section 5.2 delineates the approach for summarising and formulating design principles and spatial patterns via precedent studies. Section 5.3 underscores the logic behind devising design principles and patterns contingent upon the spatial scale and element types. Section 5.4 illustrates and discusses the development outcomes of design principles and spatial patterns across three themes, supported by examples. The complete design principles and spatial patterns are compiled separately in the Appendix A. Finally, Section 5.5 delves into the selection of the appropriate principles or patterns and the potential for integrating them to form diverse and comprehensive solutions and notes the limitations of the results.

5.1 Introduction

As emphasised in Part I, exposure to or contact with blue spaces could benefit human health in multiple ways, attracting increasing global attention. Through the comprehensive overview of existing blue-health research, a significant gap between research evidence and spatial practice has been identified. While researchers acknowledge the potential of blue space as a public health resource, specific spatial interventions are still required to harness the health benefits associated with blue spaces. Based on the collection and review of existing evidence, the previous chapter introduced a methodological framework for translating health evidence into design knowledge, summarising four critical design themes.

Subsequently, design knowledge pertaining to these four themes should be formulated to enhance the potential of individual exposure to blue space. Within these themes, spatial quantity, accessibility, and visibility aim to augment opportunities for passive contact between the public and blue spaces, enhancing public health through various potential pathways (i.e. benefiting psychological outcomes, enhancing physical activity, and promoting social interactions). Therefore, design principles and spatial patterns that aim to improve the accessibility, visibility, and quantity of blue spaces may exhibit commonalities across different regions and are often less affected by personal preferences or contextual conditions. Thus, a wealth of global cases serves as the input for developing design principles and spatial patterns.

This chapter aims to formulate design principles and spatial patterns that enhance the accessibility, visibility, and quantity of blue spaces. These serve as references and tools for practitioners seeking to apply the health benefits associated with blue spaces. Specifically, this chapter introduces a methodology that utilises worldwide precedent cases as input for developing design principles and spatial patterns. These principles and patterns are further concretised through analytical drawing and modelling techniques. Next, given the complexity of spatial elements associated with blue space, this chapter elucidates the logic and structure for developing design principles and spatial patterns, emphasising the importance of considering spatial scales and element types for comprehensive coverage and effectiveness. Lastly, this chapter showcases the process and outcomes of developing design principles and spatial patterns of three themes through illustrative examples while also delving into the synergies and trade-offs among these principles and patterns across different themes (the complete design principles and spatial patterns are presented as a distinct booklet in the Appendix A).

5.2 The Logic of Proposing Design Principles and Spatial Patterns

5.2.1 Spatial Element Groups of Blue Spaces

According to the definition of the BlueHealth[1] project, blue spaces are regarded as 'outdoor environments – either natural or manmade – that prominently feature water and are accessible to humans' (Grellier et al., 2017). Therefore, the spatial element groups of blue space extend beyond the body of water itself, encompassing diverse interlinked elements, including embankments, vegetation, recreational amenities, and public facilities. Regarding accessibility, visibility, and quantity, the surrounding environmental factors of blue spaces wield considerable influence, with factors like transportation infrastructure profoundly affecting accessibility. Hence, this study initially categorises spatial element groups associated with blue space into two distinct categories (Figure 5.1): internal components and external elements.

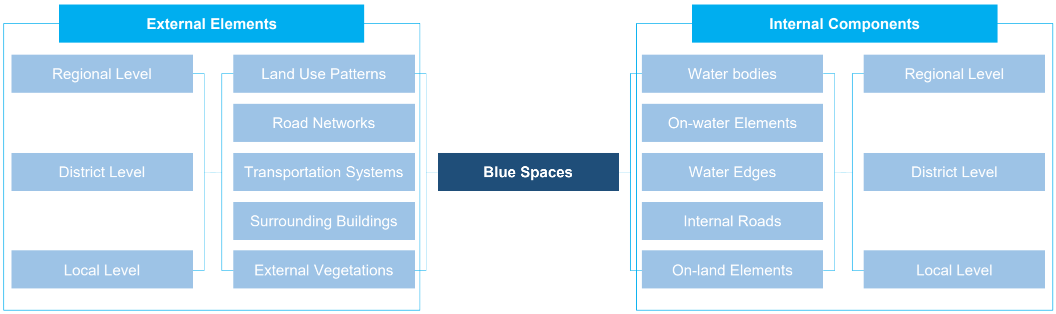


FIG. 5.1 Spatial Elements in the Design of Blue Spaces.

1 BlueHealth, funded by the EU's Horizon 2020 programme, is a pan-European research initiative that investigated the links among urban blue spaces, climate, and health.

Following Durán Vian et al.'s (2021) research on riverside classification, several groups of internal components within blue spaces are identified and summarised (Figure 5.2), including bodies of water, on-water facilities, water edges, internal roads, and on-land facilities. The spatial elements directly associated with bodies of water could be the core of blue spaces and are relatively immutable, exerting a significant influence on accessibility and visibility. For instance, spouting bodies of water offer greater spatial visibility than still ones. On-water facilities serve as crucial support for various water-based activities, facilitating direct interaction between individuals and the water.

Conversely, on-land facilities not only accommodate on-land activities (e.g. running, walking, cycling) but also possess the potential to address the varied demands of the public (e.g. resting, camping, snacking). Water edge elements constitute the transitional zone between terrestrial and aquatic ecosystems, exhibiting diverse forms shaped by environmental characteristics, thereby significantly impacting the ease of access to the water. Moreover, the spatial elements associated with internal roads notably influence public behaviour within blue spaces, impacting the opportunities for interactions with bodies of water.

On the other hand, the external element clusters of blue spaces are identified based on existing studies and frameworks (Figure 5.3) (Cerin et al., 2022; Giles-Corti et al., 2016; Rydin et al., 2012), including land use patterns, road networks, transportation systems, surrounding buildings, and vegetation. Land use patterns represent one of the fundamental features of the surrounding environments of blue spaces, and certain land uses may synergistically attract public interest in visiting a blue space. The spatial elements integrated with road and transportation systems significantly influence public visits to blue spaces. For instance, efficient public transportation can broaden the opportunities for residents to visit blue spaces (The Community Guide, 2016). The design of surrounding buildings and vegetation can serve as potential attractions for public visitation and also influence the visibility of the blue space.

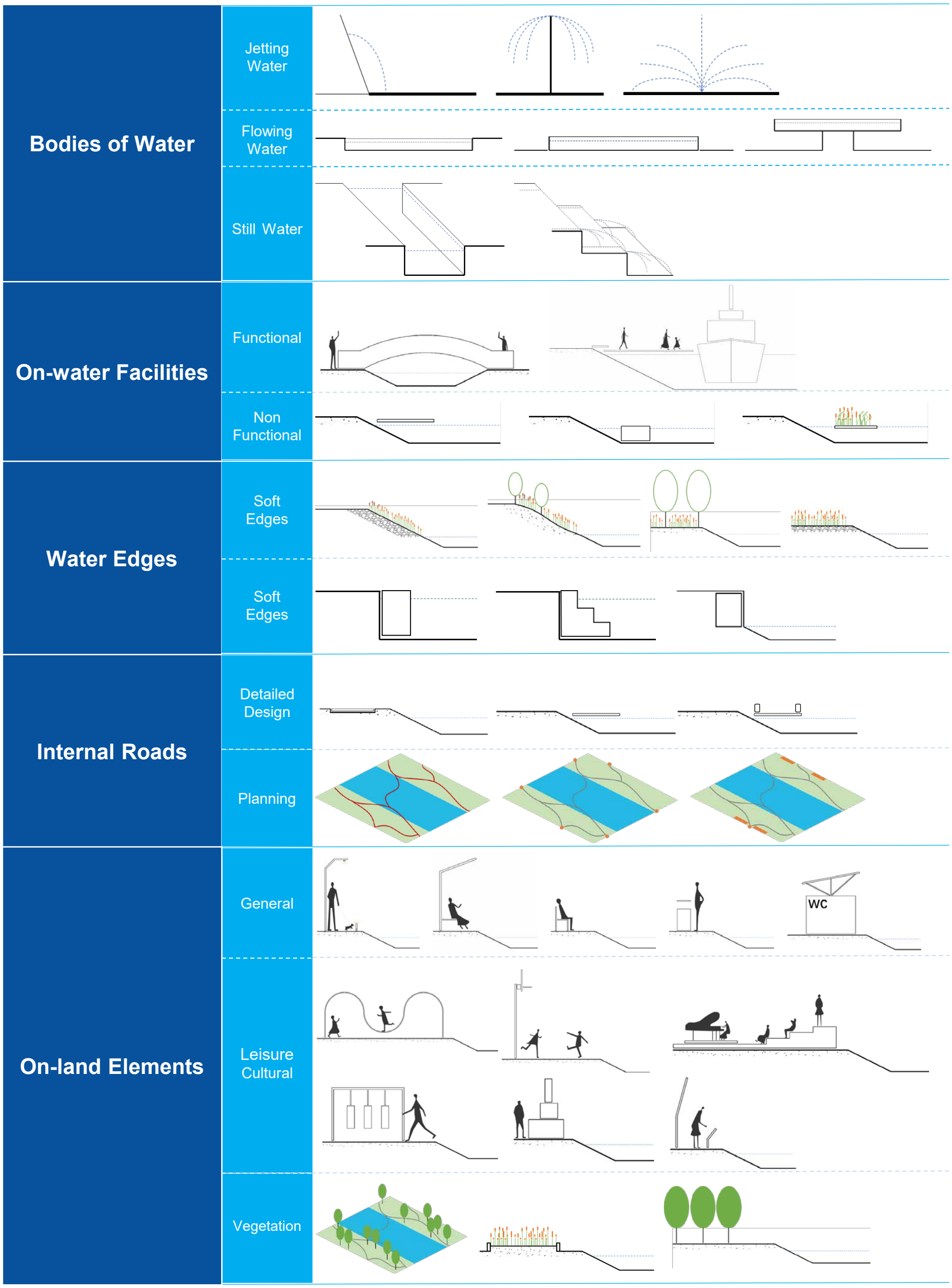


FIG. 5.2 Internal Element Clusters for Designing Blue Spaces.

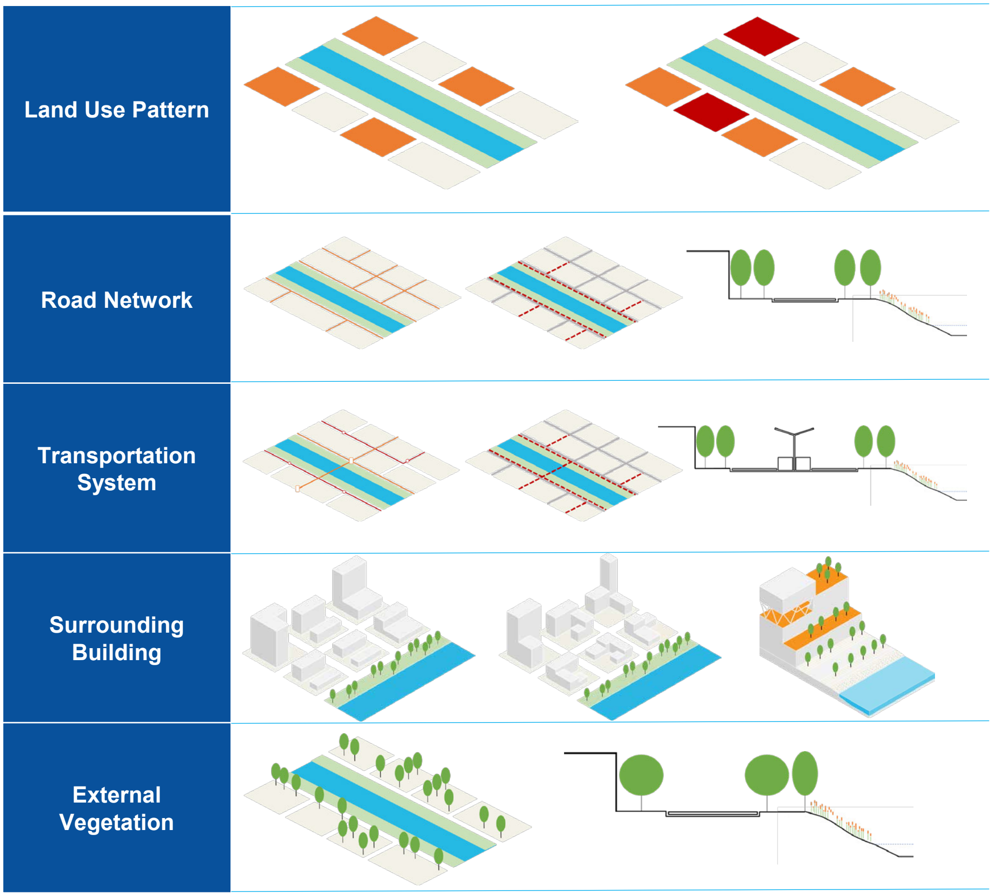


FIG. 5.3 External Element Clusters for Designing Blue Spaces.

5.2.2 Developing Design Principles and Spatial Patterns Based on Multi-scale Elements

As highlighted in the previous chapter, scale is a fundamental concept to spatial design, distinguishing design and corresponding interventions into several categories and helping practitioners tailor their projects for a potential audience (de Jong, 2006). Specifically, three scale levels are employed: local, district, and regional, aligning with the evaluation methods discussed in the previous chapter. This approach ensures coherence between methods and principles or patterns, streamlining complexity to enhance the practical potential of the design knowledge. Hence, building upon the classification of blue space spatial elements into internal and

TOC

external categories, the consideration of spatial scale is extended to categorise these elements further. Notably, while the primary internal and external element groups linked to blue space have been outlined, the specific elements corresponding to each group should also be classified based on the particular design theme. Moreover, an element group may encompass multiple specific elements spanning different scales. For instance, the group 'internal roads' could be further delineated into internal road systems and road designs, each corresponding to distinct spatial scales.

Based on the spatial elements associated with blue space classified by various design themes and scales, as well as the analysis of precedent studies, the corresponding design principles and spatial patterns are developed (Figure 5.4). While many spatial elements have been identified and categorised according to existing frameworks and design conventions, it is essential to note that their types are not fixed and may require subsequent adjustments. With the cumulation of projects and creative spatial interventions, precedent studies could also be regarded as the critical input for supplementing spatial elements of blue space, resulting in forming the 'open-ended' results highlighted in the previous chapter.

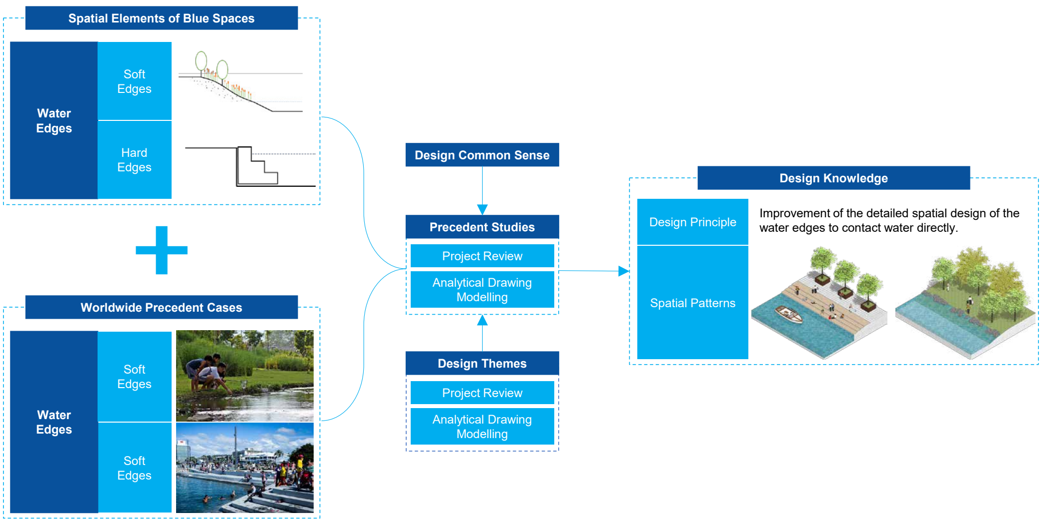


FIG. 5.4 Development of Design Knowledge Based on Spatial Elements and Precedent Studies.

5.3 Method of Precedent Studies

As previously noted, owing to the inherent objectivity of blue space accessibility, visibility, and quantity, the design principles and spatial patterns associated with these themes exhibit considerable adaptability for implementation across diverse geographic regions. Hence, global precedents serve as key references for formulating these principles and patterns. Design principles and spatial patterns must retain a degree of abstraction to enable practitioners to adapt them to particular spatial contexts. Therefore, analytical drawing and modelling are employed to capture essential attributes and commonalities of global projects, facilitating their visualisation and comprehension.

5.3.1 Project Review

Informed by Bell et al.'s (2021) research, a project review is utilised to gather worldwide exemplary practices of blue space, underpinning the subsequent development of design principles and spatial patterns. Similar to the function of literature reviews in academic fields – synthesising evidence and informing future directions, a project review aims to discern and extract knowledge or references from existing design projects that could be applied to prospective interventions. It predominantly relies on the subjective judgement of practitioners and is commonly employed in their professional practices. However, while scientific publications undergo quality control during the peer review and publication process, project reviews face limitations as not all potential projects can be included in the analysis. Therefore, an equivalent project review system is necessary to address this gap. In art and design disciplines, criticism serves as the equivalent of peer review, and this holds for architecture and landscape architecture (Bell et al., 2021). Moreover, design competitions and annual award schemes, which often involve panels of experts evaluating entries (sometimes anonymously), serve as the primary methods for sourcing projects for this research.

Professional landscape architecture journals or websites can be searched online or in libraries for project reviews that feature freshwater blue space re-/developments. These include those of worldwide professional organisations and several specialised journals that feature critical reviews of projects. Following these principles, the BlueHealth project has compiled blue space design projects spanning the past decade, making them publicly available for reference and

TOC

analysis (BlueHealth, 2020). Hence, the projects scrutinised in this study primarily originate from the Blue Health Project database, focusing on freshwater blue space. Additionally, several recent projects are included to supplement the project review data source.

Once the project database was established, the projects were categorised based on the multi-scale spatial elements of blue space. Subsequently, each project underwent critical assessment using three design themes: spatial accessibility, visibility, and quantity. Projects with the most prominent or highest-quality representation of these themes were summarised to serve as the foundation for analytical drawing and modelling.

5.3.2 Analytical Drawing/Modelling

After selecting representative projects corresponding to each design theme and blue space element, analytical drawing and modelling are employed to analyse selected projects for summarising and developing design principles and spatial patterns. It is crucial to emphasise that analytical modelling involves distilling the unique design elements, structures, and approaches implemented by the project to achieve the corresponding theme rather than merely reproducing the project itself. Thus, unlike site photos or sketches, which capture everything indiscriminately, analytical drawing/modelling is selective and fully incorporates design thinking during the analysis processes. This approach identifies recurring principles and patterns across different projects, preserving generality and enabling future adaptive applications. Moreover, the design principles with textual descriptions and spatial patterns that emphasise graphical visualisations assist practitioners in acquiring a comprehensive understanding of this design knowledge, thereby enhancing its potential for application in future projects. For instance, Figure 5.5 illustrates the development process of design principles and spatial patterns aimed at improving the accessibility of blue spaces by introducing water-contacting facilities. The first row depicts representative global projects utilised for analytical drawing/modelling, while the second row showcases the resultant design principles and spatial patterns distilled from these projects. This approach reveals that the principles and patterns capture essential project information, allowing for modest generalisations.

FIG. 5.5 Developing Design Principles and Spatial Patterns Based on Global Cases.

TOC

5.4 Examples of Design Principles and Spatial Patterns

5.4.1 Design Principles and Spatial Patterns: Quantity

Unlike spatial accessibility and visibility, the design principles and spatial patterns related to the increasing number of blue spaces are relatively simple and solely tied to the spatial elements grouped as bodies of water. According to the scale levels, three design principles aimed at increasing the quantity of blue space are proposed: (1) re-connecting/developing water systems, (2) expanding existing bodies of water, and (3) creating new freshwater blue spaces. For each principle, several specific spatial patterns are suggested to provide practical guidance. For example, the principle of re-connecting/developing water systems can be further translated into two spatial patterns (Figure 5.6): (1) revitalising historical bodies of water and (2) creating temporary blue spaces aligned with other concerns, such as excess precipitation and flood protection.

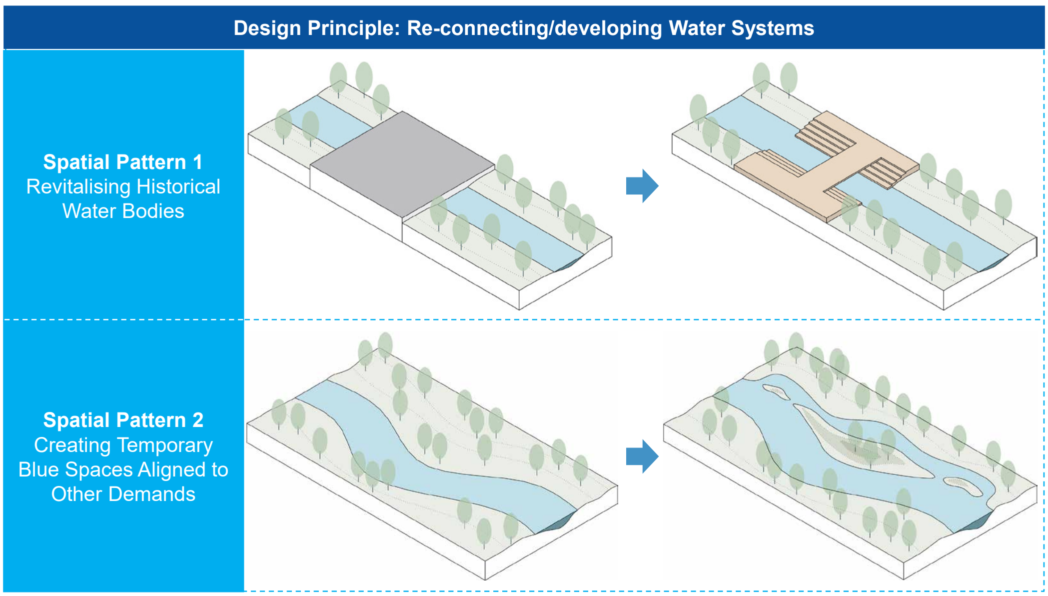


FIG. 5.6 Examples of Design Knowledge Related to Spatial Quantity.

On the other hand, drawing on Haase's (2015) research, a compilation of urban blue space typologies is summarised and provided to complement design principles and spatial patterns. This endeavour aims to support practitioners in applying principles and patterns to increase the number of blue spaces. Specifically, freshwater blue spaces are initially categorised into two groups based on the spatial morphological characteristics of bodies of water: linear bodies of water and planar bodies of water (Figure 5.7). Linear bodies of water encompass rivers, creeks, and canals, whereas planar bodies of water include lakes, wetlands, ponds, fountains, and reservoirs. Next, to assist practitioners in understanding the potential implementation challenges of expanding blue spaces, two categories – natural and artificial – are used to distinguish whether the blue space is human-made (Figure 5.7). The findings reveal that rivers, creeks, lakes, and wetlands are classified as natural bodies of water, whereas canals, reservoirs, ponds, and fountains fall under artificial bodies of water.

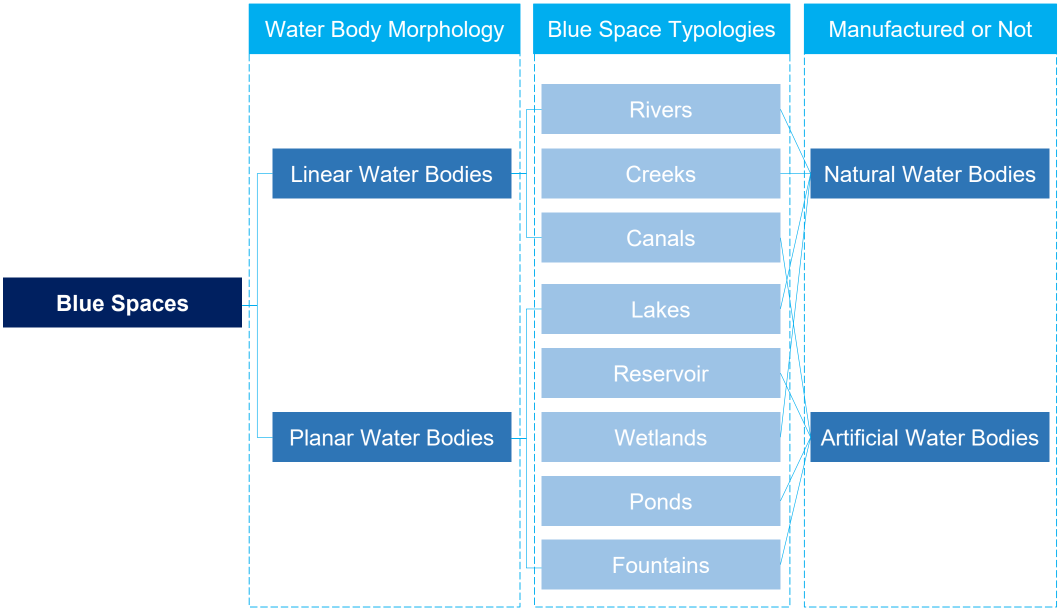


FIG. 5.7 Typologies of Freshwater Blue Spaces.

5.4.2 Design Principles and Spatial Patterns: Accessibility

In contrast to the elements associated with spatial quantity, those concerning accessibility are more complex. After screening, nearly all spatial element groups, except for those related to external vegetation, are identified as foundational in developing tailored design principles and spatial patterns for spatial accessibility (Figure 5.8). Next, drawing inspiration from the precedent studies, each group of related elements is broken down into specific components. For example, the bodies of water group is further deconstructed into blue space quantity and distribution at the regional scale and bodies of water at the local scale. As mentioned in the previous section, one element group could compass several elements from various scale levels. Subsequently, analytical drawing and modelling are employed to extract design principles and spatial patterns for each element. This process necessitates the researcher's design thinking to discern the core contents and structure of the case, thereby formulating the corresponding design principles and spatial patterns.

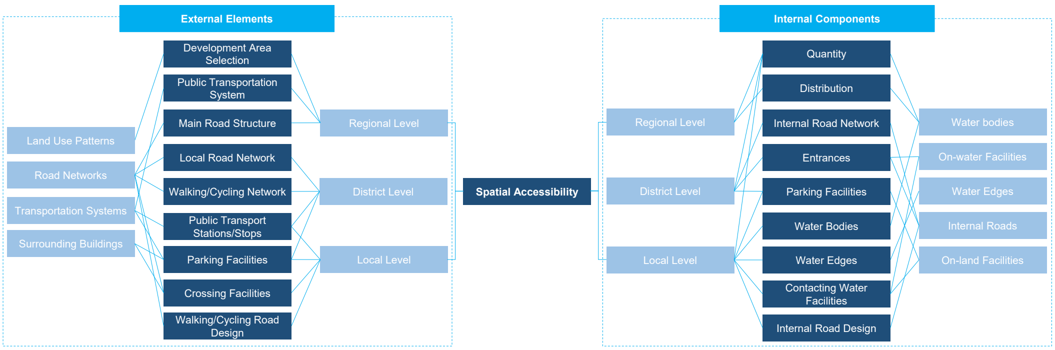


FIG. 5.8 Spatial Elements for Developing Design Principles and Spatial Patterns Related to Blue Space Accessibility.

In this section, the development processes and outcomes of design principles and spatial patterns for road design to enhance the spatial accessibility of blue spaces are exemplified (Figure 5.9). Here, the design principle is 'improvement of the detailed design of the internal roads to contact water directly, such as road forms, materials, and handrails'. Next, three distinct spatial patterns corresponding to the design principles are delineated based on existing projects. Spatial Pattern 1 entails the configuration of roads directly over bodies of water, which links to the road forms. Spatial Pattern 2 involves using road materials to render the road surface more transparent, enhancing the hydrophilicity of bodies of water. Spatial Pattern 3 focuses on road handrails, advocating for implementing lower railings or transparent materials to promote physical contact with bodies of water.

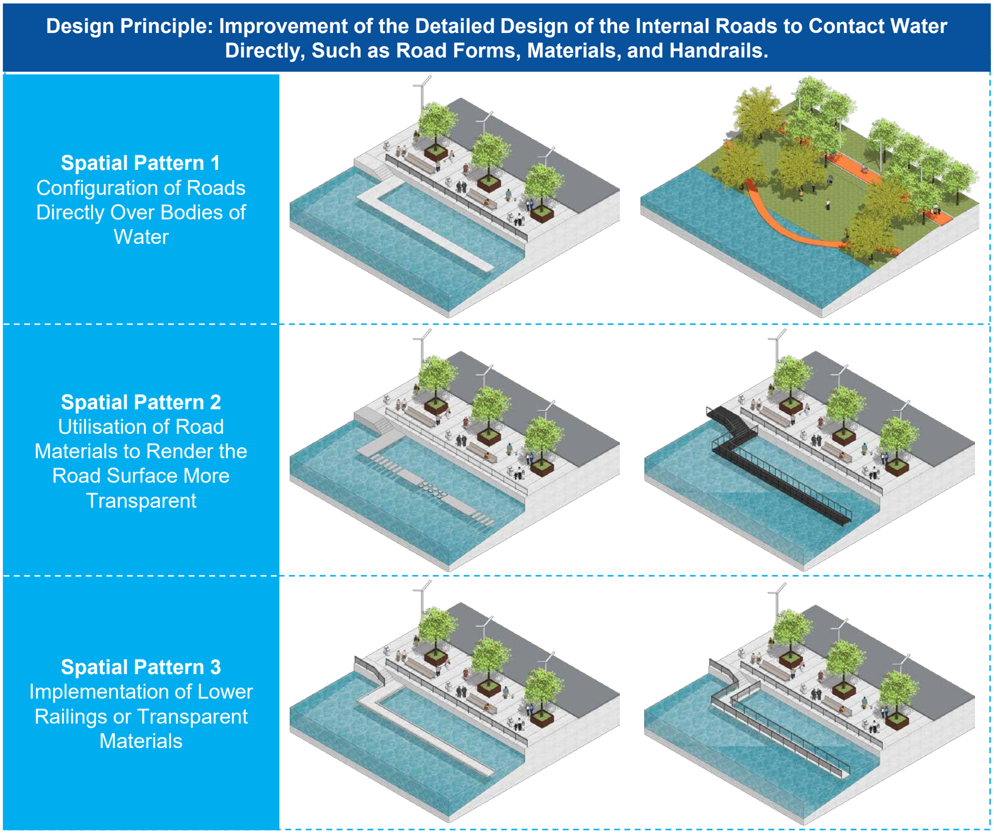


FIG. 5.9 Examples of Design Knowledge Related to Spatial Accessibility.

5.4.3 Design Principles and Spatial Patterns: Visibility

Similar to spatial accessibility, the study identifies most spatial element groups except land-use patterns and transportation systems to formulate design principles and spatial patterns related to visibility (Figure 5.10). Then, the chosen spatial element groups of blue spaces are divided into specific components, such as surrounding buildings being conceptualised into viewing corridors at the regional scale, building layout at the district scale, and building design at the local scale. By integrating design thinking with analytical modelling and drawing based on existing cases, the design principles and spatial patterns for enhancing the blue visibility of each spatial element are formulated.

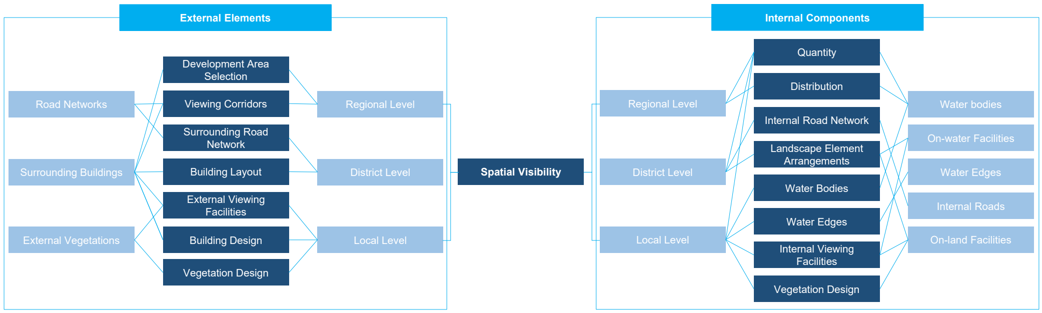


FIG. 5.10 Spatial Elements for Developing Design Principles and Spatial Patterns Related to Blue Space Visibility.

To enhance clarity, echoing the previous section on spatial accessibility, this section also emphasises the structure and development of the principles and patterns, providing limited examples for illustrative purposes. The principles and patterns related to building design are shown here. Specifically, the design principle pertains to the ‘enhancement of the detailed design of surrounding buildings to amplify water visibility’. In alignment with this principle, three spatial patterns are proposed (Figure 5.11), drawing from diverse perspectives and existing cases: (1) enlarging the dimensions of windows and doors; (2) integrating viewing platforms within buildings, particularly high-rise structures; and (3) optimising building forms to maximise the blue view, such as incorporating exterior cascading terraces.

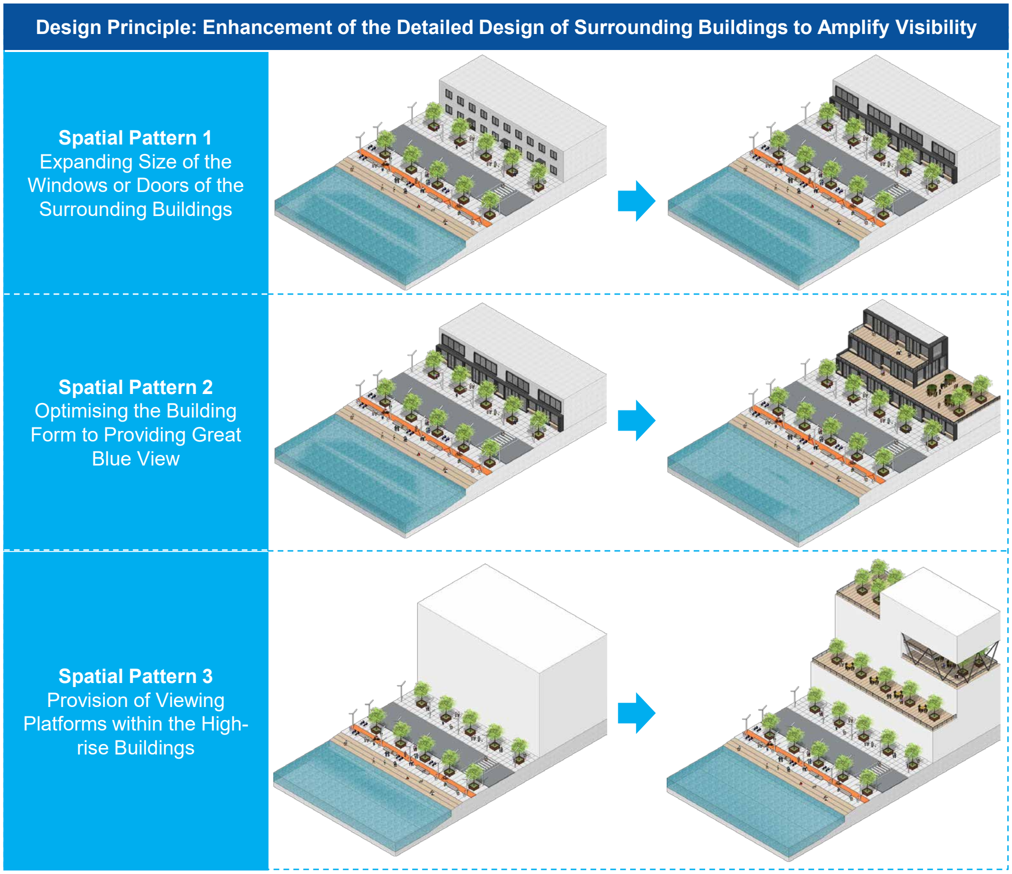


FIG. 5.11 Examples of Design Knowledge Related to Spatial Visibility.

TOC

5.5 Discussion

5.5.1 Selections of Suitable Design Principles and Spatial Patterns

In this chapter, the process and outcome of the formulation of the design principles and spatial patterns related to three design themes (i.e. quantity, accessibility, visibility) have been documented and illustrated with examples. Analogous to the evaluation methods presented in the previous chapter, it is imperative to discuss how to select appropriate principles and patterns in practical applications. Certainly, the three design themes could significantly influence the practitioner's selection of principles and patterns, which is contingent upon both the design intentions and the current site conditions. For instance, increasing the quantity of blue space is undeniably the most straightforward approach to augmenting the potential for blue space exposure. However, it is also the most challenging to implement in practice, primarily due to significant constraints imposed by environmental factors. In urban settings, bodies of water are often considered foundational elements of the city and are challenging to modify.

While single principles or patterns may centre on distinct design themes and spatial elements, there are possibilities where combining these principles and patterns can potentially yield more impactful outcomes. For instance, at the regional scale, principles and patterns, such as adjusting the main road structure to enhance blue space accessibility and constructing view corridors to benefit visibility, could be combined, amplifying their effects with minimal effort. On the other hand, the design principles and spatial patterns could be joined to comprise a menu-style design tool, allowing practitioners to tailor combinations of principles and patterns according to diverse scale levels. The diverse and flexible combinations of principles and patterns could provide myriad possibilities for blue space design, which is crucial in urban environments packed with potential constraints and catering to various design intentions. As illustrated in Figure 5.12, the myriad combinations could yield diverse possibilities, ranging from the distribution of blue spaces to the design of water edges or contact facilities. In this case, the patterns at the larger scale do not determine the choice of patterns at the smaller scale but, instead, enable the creation of different possibilities through various paths.

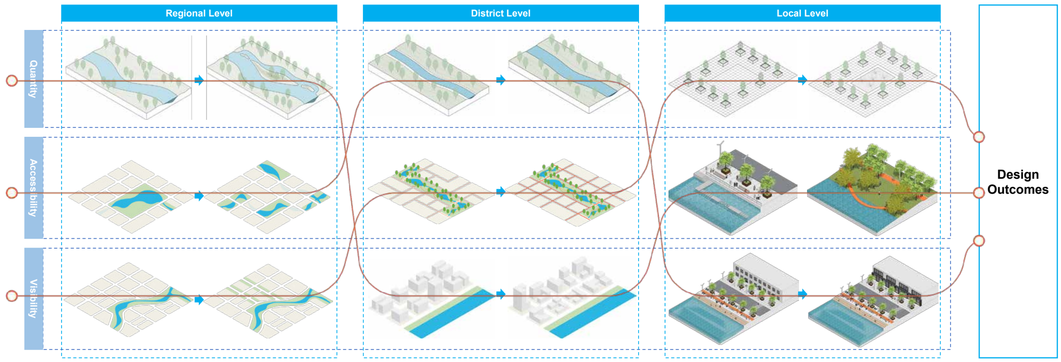


FIG. 5.12 Rich Combination Possibilities Among Different Principles and Patterns.

Each design principle is often conceptualised into multiple spatial patterns, so the process of selecting a specific pattern for application in practice is not a simple linear structure but could be regarded instead as an iterative and circular process that encompasses several attempts by practitioners. On the other hand, the application of design principles and spatial patterns often involves trade-offs, particularly when considering other objectives. For instance, when implementing principles or patterns aimed at adapting the structure of public transportation systems and main roads to enhance blue accessibility, it is essential to consider the risk of traffic congestion. For example, roads traversing bodies of water require additional investment and focusing solely on roads alongside the water may impact traffic flow. Therefore, designers need to experiment with different principles and patterns during design, allowing them to fully assess the challenges and issues arising from contextualising various principles and patterns on sites. This endeavour can also stimulate practitioners' creativity, leading to innovative solutions and the potential development of new principles and patterns.

5.5.2 Strengths and Limitations

Based on the four design themes distilled from the blue-health research evidence in Part I, this chapter predominantly concentrated on the three themes of accessibility, visibility, and quantity. It elucidated the procedures involved in formulating design principles and spatial patterns pertinent to these themes by synthesising spatial elements and employing project review and analytical modelling, exemplified through various cases. The advantages of the translation process and its results (i.e. design principles and spatial patterns) lie in four aspects: (1) presenting design knowledge in the form of diagrams significantly addresses the limitation of practical application resulting from the generic nature of public health evidence, thereby offering a viable avenue for translating evidence into practice; (2) the design knowledge is derived from existing global cases, which significantly ensures their practicality for implementation elsewhere; (3) principles and patterns entail a certain degree of abstraction in visualisations and are organised by spatial scale and element types, enabling practitioners to remain flexible and respond to diverse design intentions; and (4) the menu-style design knowledge could support multi-stakeholder interaction and public design engagement.

On the other hand, it is essential to acknowledge certain limitations: (1) the current collection of precedents and evidence is limited, which prevents the exhaustive listing of all potential possibilities for principles and patterns; (2) the process of developing design knowledge relies on utilising the design thinking and subjective judgments of researchers, which may introduce potential bias due to the limited number of researchers involved; (3) visualised principles and patterns offer convenience to designers but may impose limitations on creativity, meaning practitioners should apply them critically in practice to avoid stifling innovation.

5.6 Conclusion

This chapter employed precedent studies, including project reviews and analytical drawing/modelling, to illustrate the process of translating abstract design themes (i.e. accessibility, visibility, quantity) derived from health evidence into practical design principles and spatial patterns. It clarified the logic behind the development of design knowledge, emphasising the formulation and structuring of design principles and spatial patterns grounded in spatial elements and scales. Accordingly, this chapter identified multi-scale spatial elements pertinent to the three design themes and elucidated the process of distilling and refining design knowledge through global cases.

Notably, this chapter presents only a subset of the design principles and spatial patterns, and the rest are compiled into a separate book in the Appendix A, facilitating easy access and utilisation for practitioners. The proposed design principles and patterns can promote the harnessing of the public health benefits of blue space by enhancing the three design themes. They maintain a level of flexibility, enabling practitioners to explore various possibilities in applications, thereby furnishing them with direct tools and references for their projects. Nevertheless, the constraints stemming from limited project data and the subjective nature of translation necessitate ongoing research to continuously synthesise and update findings based on emerging cases and evidence. Future studies should actively employ these findings to validate their potential application in urban areas worldwide. Additionally, since the design themes of accessibility, visibility, and quantity emphasise the objective characteristics of blue spaces, the generation of design knowledge for these categories is derived from summarising worldwide cases. In contrast, the subjective characteristics of spatial quality necessitate a targeted translation of design knowledge based on site-specific evidence, which is detailed in the following chapter.

6 Design Principles and Spatial Patterns for Spatial Quality

Exploring the Associations of Blue Space Spatial Quality with Recreational Physical Activities Using Crowdsourced Data

This chapter aims to translate site evidence into design knowledge for improving blue space quality and facilitating the implementation of its health benefits. As outlined in Part I, blue spaces connect to human health through four primary pathways. Due to the complexity of addressing these pathways, this chapter focuses on promoting physical activity as a proxy for health outcomes. Using crowdsourced data and machine learning techniques, this chapter examines the relationship between blue space quality and physical activity at the street level in Rotterdam, with attention to variations in activity types and population groups. The findings reveal that spatial quality factors, such as green view index, openness, land-use mix, and street connectivity, consistently influence physical activity, though the magnitude varies. Additionally, factors like urbanisation and spatial complexity show mixed effects. Analysis by age groups indicates that running patterns vary across age demographics, with spatial quality factors impacting activities differently among these groups. Based on these insights, tailored design principles and spatial patterns are proposed to meet the environmental needs of different activities and age groups. These results contribute to understanding the blue-health mechanism and provide practical guidance for designing healthy blue spaces.

6.1 Introduction

As highlighted in Part I, the health benefits of natural environments have been widely discussed in recent decades, given that the rapid expansion of urban space has overtaken natural areas and poses a threat related to chronic lifestyle-related diseases (Bratman et al., 2019; Hartig et al., 2014; Hartig & Kahn, 2016). While substantial evidence supports the green-health nexus, integrating blue space into health-supportive planning measures and strategies is underexplored despite the increasing recognition of its health benefits (Hunter et al., 2023; White et al., 2020; Zhang et al., 2022). In Part I, this study introduced a methodological framework for translating the health benefits of blue spaces into practical design knowledge by systematically summarising existing evidence. Thus, four main design themes (i.e. accessibility, visibility, quantity, and quality) are identified to organise the development of design knowledge. Accessibility, visibility, and quantity focus primarily on the objective characteristics of blue spaces. Accordingly, the corresponding design knowledge includes design principles, spatial patterns, and evaluation methods.

The previous two chapters elucidated the development of design knowledge concerning accessibility, visibility, and quantity, facilitated by a compilation of interdisciplinary tools and a synthesis of worldwide precedent cases. In contrast, spatial quality is often closely linked to individual perceptions, necessitating that the design knowledge pertaining to it be supported by local evidence. This evidence should elucidate the relationship between blue space quality and various health-promoting pathways, such as identifying specific quality factors of blue spaces that confer significant psychological benefits and enhance public physical activity. Given the complexity of the four pathways, this chapter uses the promotion of physical activity as an illustrative example to explore the potential for formulating design knowledge aimed at enhancing blue space quality.

The promotion of physical activity, a fundamental pathway connecting blue spaces and public health, has attracted increasing attention among practitioners as a potential method to harness the health benefits associated with these spaces (Remme et al., 2021). Accordingly, several emerging urban planning and design concepts, such as walkability and the development of running/cycling-friendly cities, underscore the importance of this pathway in addressing urban health issues (UN General Assembly, 2015). However, translating these planning concepts into practical actions requires a detailed and targeted understanding of the relationship between the spatial quality of blue spaces and physical activity, providing the basis for the proposal of targeted design strategies (Huang, Tian et al., 2023). On the other hand, the emergence of multi-source data and advanced technologies (e.g. machine learning and computer vision techniques) makes it possible to investigate the association of the spatial quality of blue spaces with physical activity at the city level and lends support to the synergy between local evidence and customised design strategies.

6.1.1 Associations of the Spatial Quality of Blue Space with Physical Activity

Existing research has indicated that the association between blue space and physical activity is modified by the spatial quality factors of blue space, including surrounding environmental characteristics, spatial layout or organisation, blue space type, and traffic conditions (McDougall et al., 2020; White et al., 2020; Zhang et al., 2023b). These studies have examined changes in people's behavioural preferences and choices through experimental manipulation or on-site observations of changes in blue space quality. The findings indicate that blue spaces, characterised by cleanliness, naturalness, safety, and biodiversity, are more likely to attract individuals to engage in physical activities (Fisher et al., 2021; Higgins et al., 2019; Vert, Carrasco-Turigas, et al., 2019; Vert, Nieuwenhuijsen, et al., 2019; Wilson et al., 1995; Wyles et al., 2016). However, the current study on blue spaces is limited and valuable insights can be gained from studies on green spaces and urban environments in general. Factors such as vegetation, land-use mix, building density, and street connectivity in the areas surrounding blue spaces could also influence running and cycling activity (Kerr et al., 2016; Ki & Lee, 2021; Liu et al., 2023; Lu, 2019; Orellana & Guerrero, 2019; Yang et al., 2019).

On the other hand, individual-level differences give rise to varying requirements for physical activity environments, a distinction most intuitively apparent in relation to age groups. An expanding body of research indicates that individuals across different age groups exhibit distinct environmental perceptions and preferences for physical activity, which is crucial for vulnerable older populations with limited opportunities for exercise (Laddu et al., 2021). This factor underscores the necessity for more comprehensive evidence to address the physical activity needs of these groups and eradicate inequalities in physical activity opportunities.

Notably, previous studies have often used traditional methods of site interviews, questionnaires, and field observations to link the spatial quality of blue space to people's physical activity (Akpinar, 2016; Mishra et al., 2020; Vert et al., 2019a).

While offering insightful action-related support for spatial interventions, these traditional methods are time-consuming, labour-intensive, and only apply to small-scale research participants or a small research area (e.g. residential neighbourhoods). Due to the difficulty in data acquisition, there is little evidence of the relationship between the spatial quality of blue space and physical activity at the population/city level. This challenge limits the translation of research evidence into practical urban designs and planning strategies to construct exercise-supportive and health-promoting urban environments (Chen et al., 2022; WHO, 2021; Zhang et al., 2022).

6.1.2 The Applications of Volunteered Geographic Information (VGI) and Street View Image (SVI) in Nature-health Research

Driven by the advancement of machine learning and computer vision techniques, the audition and evaluation of health-supportive urban environments through large-scale street view images (SVIs) are becoming realistic and gradually replacing on-the-spot observations (Biljecki & Ito, 2021; Wang, 2023). An SVI creates a continuous 360-degree image of urban environments, allowing people to understand the subjective and objective characteristics of the surrounding environments from an eye level (Dong et al., 2023; Tang & Long, 2019). Specifically, objective characteristics of the urban environments are mainly described by the types and quantities of elements in SVI, such as the green view index (GVI), the richness of public facilities, openness, and complexity (Ki & Lee, 2021; Zhang et al., 2023a; Zhou et al., 2022). Compared with objective characteristics, the subjective evaluation of SVI is an emerging technique using a participatory approach and machine learning to build a connection with human perception and well-being. A representative example is the MIT Place Pulse project, which uses global SVI data and a human-machine adversarial scoring framework (Zhang et al., 2018).

In addition to advancements in measuring urban environments, the trajectory data of physical activity could accurately represent people’s usage of urban environments. Traditional approaches for measuring physical activity rely heavily on on-site observation, such as the well-known observational analysis of population usage patterns in public spaces (Gehl, 2013). With the introduction of GPS-based accelerators, public participation GIS (PPGIS) and volunteered geographic information (VGI), it is possible to collect more accurate behavioural and activity path–based data (Gerstenberg et al., 2020; Jansen et al., 2018; Lee & Sener, 2021). Among these tools, VGI offers distinct advantages compared to traditional approaches, including its independence from additional instrumentation, cost, effectiveness, and the capacity to depict city-level geo-located activity paths (Huang, Tian et al., 2023). These attributes have made it a preferred choice among urban planning researchers and practitioners in multiple fields, such as urban analysis, active mobility, health and well-being, and behavioural or landscape preferences.

Recent studies have tried integrating SVI and VGI data to analyse and understand people's behaviour patterns and preferences. For example, Dong et al. (2023) investigate the correlation between comprehensive multi-scale street environment features and running behaviour in Boston. Huang, Tian et al. (2023) adopt similar methods to explore the connection between Helsinki's street environments and running intensity. The great potential of SVI and VGI methods lends support to examining the associations between spatial characteristics of urban environments and people's behaviour or activity at a larger geographical scale and a more general population level, providing a solid basis for developing exercise-supportive and health-promoting design knowledge.

6.1.3 Knowledge Gaps and Research Questions

The primary objective of this chapter is to demonstrate the processes involved in collecting local evidence to develop design knowledge that enhances blue space quality, thereby facilitating the implementation of blue space health benefits. Additionally, the exploration in this chapter addresses some of the knowledge gaps identified in existing blue-health research. First, most studies explore the spatial factors of general urban environments or green spaces and their associations with recreational exercises (Akpinar, 2016; Dong et al., 2023; Yang et al., 2022). In contrast, less is known about the associations of physical activity in or near blue spaces, even though they are considered ideal places for exercises. Second, existing studies mainly analyse a single exercise type or combine different types of exercises (Huang, Tian, et al., 2023; Jiang et al., 2022; Koo et al., 2022; Liu et al., 2016; Lu et al., 2019). However, understanding the shared and distinct requirements for spatial quality across all sorts of activities is essential. This understanding provides designers with thorough information to inform their decision-making process. Third, beyond the environmental demands specific to different types of physical activities, individual-level differences give rise to varying requirements for physical activity environments, a distinction most intuitively apparent in age groups. An expanding body of research indicates that individuals across different age groups exhibit distinct environmental perceptions and preferences for physical activity, which is particularly crucial for vulnerable older populations with limited physical activity opportunities (Laddu et al., 2021). Last, echoing the primary objective, despite emerging evidence on the spatial patterns of physical activity and environmental predictors, relevant research needs to be translated into practical knowledge and steps to create exercise-supportive and health-promoting urban environments (WHO, 2021; Zhang et al., 2022).

Utilising crowdsourced data that combines the SVIs of blue spaces with VGI data on physical activity (i.e. running and cycling) from the Strava platform, this study investigates the relationship between the spatial quality of blue spaces and population-level physical activities in Rotterdam, aiming to translate these local findings into practical design knowledge. Four questions are investigated in this chapter: (1) How are the spatial quality factors of blue spaces associated with running and cycling activities? (2) Do the associations between these environmental factors and recreational exercises differ between two main types of exercises (i.e. running versus cycling) depending on their statistical distribution and spatial autocorrelation (i.e. similar exercise patterns in geographically adjacent areas)? (3) Does the relationship between these spatial quality factors and recreational running vary among different age groups? (4) What are the key lessons to be learned from implementing exercise-supportive and health-promoting blue spaces and advancing evidence-based design approaches?

6.2 Research Data and Methods

6.2.1 Study Area and Study Design

To achieve the research objectives, this chapter uses Rotterdam as a case study and outlines a six-step methodology, as illustrated in Figure 6.1. First, the street-level physical activity (i.e. running and cycling) counts are obtained from the Strava platform. Second, the SVIs for each sample point on street segments of blue spaces are collected, and the pixel ratio of each eye-level spatial quality factor is calculated. Third, multi-sourced spatial quality factors (i.e. built environment, street connectivity, and neighbourhood composition) that could influence running and cycling activities are collected and geo-analysed. Fourth, a mapping analysis is conducted to assess the spatial distribution of recreational running in blue spaces across different age groups. Fifth, the relationships between various spatial quality factors of blue spaces and the activities of running and cycling are explored using ordinary least squares (OLS), negative binomial, and spatial regression models, considering the two distinct physical activity types. Sixth, focusing on different age groups and using running as an example, the OLS and spatial regression models are employed to analyse the correlations between environmental factors and recreational running. In contrast, the geographically weighted regression (GWR) model is used to examine the spatial heterogeneity of visual perception factors influencing running. Finally, based on the outcomes of these analyses, tailored principles and patterns for planning and designing exercise-supportive and health-promoting blue spaces are developed.

To effectively demonstrate the generation of quality-related design knowledge and the potential of the novel tool integrating VGI and SVI data, various models are employed during the evidence-collection phase to address distinct considerations. OLS, negative binomial (NB), and spatial regression models are utilised to analyse and compare the variations in the relationship between two different physical activities and spatial quality. To avoid unnecessary complexity, this chapter focuses solely on examining the differences in blue space quality among various demographic groups during running. Additionally, the study employs the GWR model to investigate the spatial heterogeneity of the impact that eye-level factors of spatial quality have on the running behaviour of different age groups.

It is important to note that design knowledge can be considered an open-ended outcome. Therefore, this chapter focuses on collecting and translating site evidence into design knowledge for enhancing the quality of blue spaces rather than providing an exhaustive list of all possible outcomes. Additionally, to minimise the impact of detailed descriptions and interpretations of model results on the generation of design knowledge, this chapter provides only a succinct overview. A comprehensive account of these results and their interpretations is available in the supplementary materials of Zhang et al. 2024.

Rotterdam, the second largest city in the Netherlands and a key European port city, is located in the province of South Holland, which has a temperate oceanic climate. It covers 326 km^2 and has a population of more than 6 million (Frantzeskaki & Tilie, 2014). As a commercial and industrial hub of the Nieuwe Maas River, Rotterdam is predominantly located on riverbanks, polders and reclaimed land. Approximately 85 % of the land lies below sea level, fostering extensive experience in water management and abundant blue space resources. Blue spaces, therefore, have become a central venue for people’s daily activities. Governments have also initiated several projects to facilitate the multifunctional utilisation of blue spaces, with the city vision of ‘living with water’ (de Graaf & der Brugge, 2010; Dunn et al., 2017). Moreover, the running and cycling culture is prevalent in the Netherlands.

Cycling trips account for over a quarter of the total trips for Dutch residents. Governments have also developed a comprehensive running and bicycle transportation network since the 1970s, especially cycling lanes spanning the entire country. Running and cycling is regarded as a satisfactory form of daily exercises across different social groups (Fraser & Lock, 2011; Pucher & Buehler, 2008). Therefore, the selection of Rotterdam as the case will set a benchmark for developing exercise-supportive healthy blue spaces in other cities and regions.

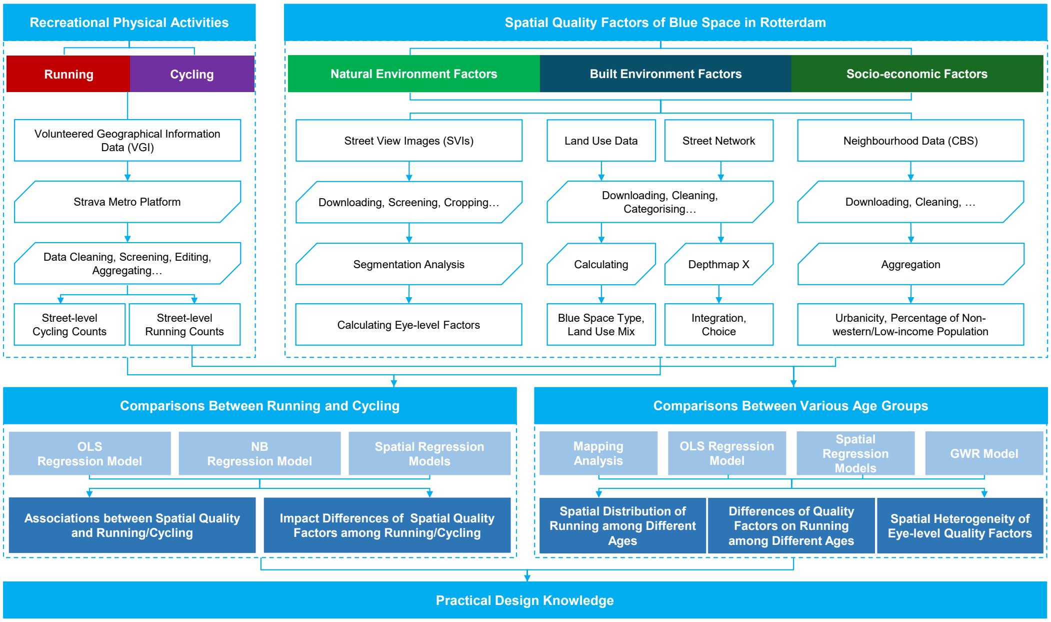


FIG. 6.1 Research Framework.

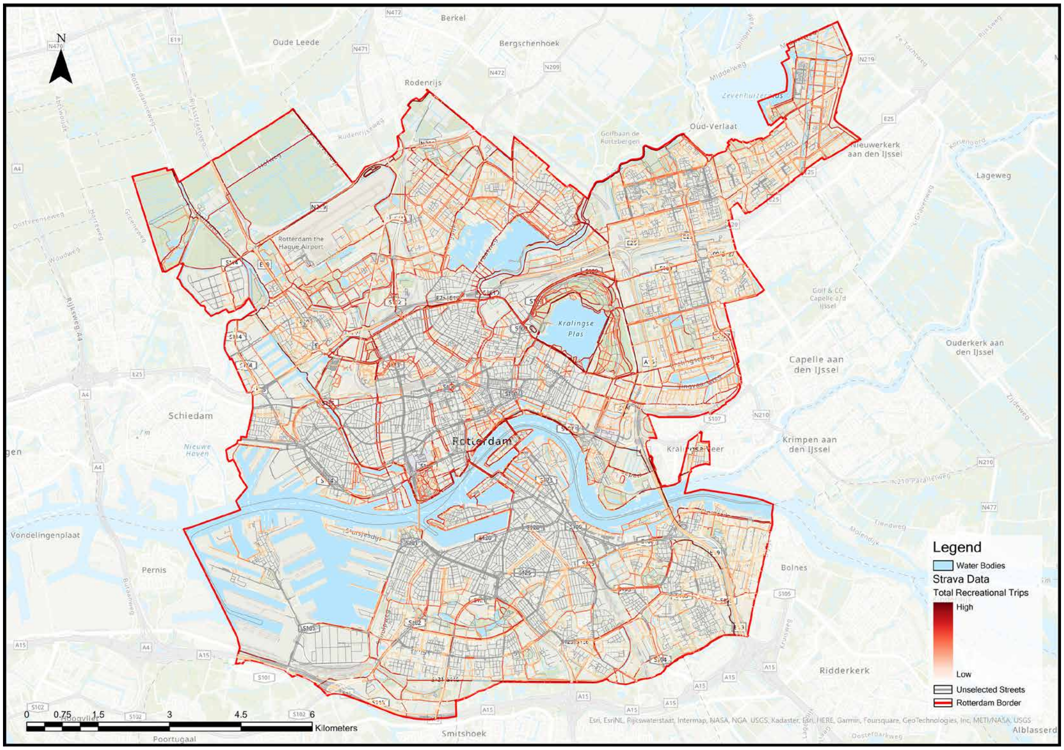
TOC

6.2.2 Data Description

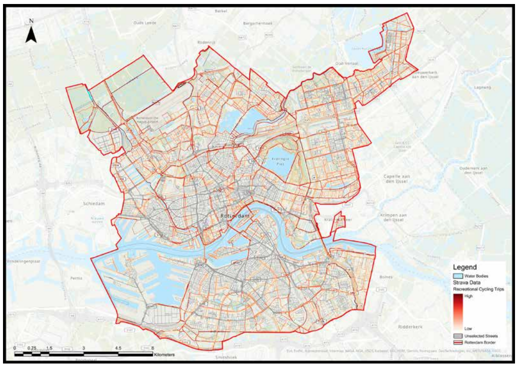
6.2.2.1 Dependent Variables: Running and Cycling Counts at the Street Segment Level

The dependent variables are the recreational running and cycling counts based on street segments drawn from VGI. VGI data are based on the Strava platform, a GPS-based mobile fitness application where over 1 billion registered users upload their daily recreational running or cycling routes. The running and cycling records within the city of Rotterdam for 2021 are obtained for analysis. Following privacy considerations, personal GPS trajectory data of running and cycling are aggregated to the street level and presented numerically. The street segments adjacent to blue spaces are selected to investigate the associations between recreational running and cycling and the spatial quality of blue spaces. Specifically, a 50m buffer around bodies of water is computed to determine the targeted street segments. This approach results in a final sample of 24,050 street segments with 37,978,305 cycling records and 35,685,390 running records for the modelling analysis (Figure 6.2). Moreover, to investigate variations in the impact of spatial quality across different age groups, the running data are further categorised according to four main age groups (i.e. 18–34, 35–54, 55–64, 65 plus).

THE TOTAL COUNTS OF RECREATIONAL CYCLING AND RUNNING AT STREET SEGMENTS



THE COUNTS OF CYCLING AT STREET SEGMENTS



THE COUNTS OF RUNNING AT STREET SEGMENTS

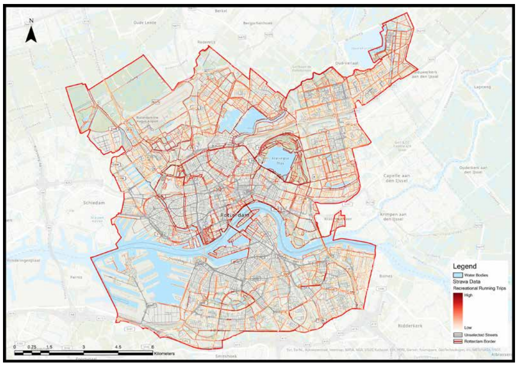


FIG. 6.2 Cycling and Running Counts at the Level of Street Segments in Rotterdam, the Netherlands.

6.2.2.2 Covariates at the Street Segment Level: Spatial Quality Factors

Spatial quality factors of natural environments. Four factors related to the spatial quality of natural environments in blue space are selected to estimate the running and cycling counts, that is, the blue space type, water view index (WVI), GVI, and openness (Dai et al., 2021; Huang, Tian et al., 2023; Jeon & Woo, 2023; Ki & Lee, 2021). Previous research has suggested that individuals exhibit varying preferences for visiting and using different types of blue spaces, with large-scale blue spaces being perceived as more ideal for conducting non-sedentary activities and symbolic in building place identity (McDougall et al., 2022; Völker & Kistemann, 2013). For this consideration, a categorical variable encompassing three types of blue space, i.e. the Nieuwe Maas River, recreational blue spaces, and other blue spaces, is created and included in the analysis (CBS, 2023). The Nieuwe Maas River is treated as a separate category due to its considerable size and symbolic significance to Rotterdam (Rijkswaterstaat, 2023), while recreational blue spaces are defined as small bodies of water in parks and other public recreational spaces. The 'other blue spaces' type, including inland canals and rivers, is the reference term in the statistical analysis.

WVI, GVI, and openness are the indicators of the eye-level spatial quality of blue spaces, which have been derived through a combination of deep-learning techniques and SVIs. WVI and GVI measure the proportion of water and vegetation elements (such as trees, plants, and grass) in people's line of sight, while openness estimates the proportion of visible sky. The calculation of these indicators involves four specific steps (Figure 6.3). First, sampling points at 30-metre intervals along the street segments are generated in preparation for obtaining the SVI. By inputting the coordinate data of the generated points into a Python script relying on the SVI application programming interface (API), a total of 36,970 SVIs of 1,500 by 750 pixels are taken with a zero-degree pitch angle, covering entire study street segments in Rotterdam. The sampling intervals and pitch angle selection draw on existing studies of walkability and run-ability, which could be approximately identical to the eye-level perceptions of the urban environment (Jeon & Woo, 2023; Tang & Long, 2019).

Because the 360-degree SVIs could inevitably show distortion at the edge area, resulting in inaccurate results of subsequent segmentation, a crop-out method is applied to handle the distorted images. The indicators used for cropping follow the individual's field of view, including a 270-degree horizontal angle and a 150-degree vertical angle (Jeon & Woo, 2023; Ki & Lee, 2021). Subsequently, the cropped SVIs are analysed through a deep-learning model of a conventional neural network (FCN-8s) for semantic segmentation to identify the features (such as water, plants, and sky) within the images (Helbich et al. (2019). ADE20K dataset, a collection of annotated images with 151 feature categories, is adopted to train the model (Zhou et al., 2019). Finally, WVI, GVI, and openness are calculated by the proportion of pixels for water, vegetation, and sky features to the total image pixels, respectively. For each street segment, the WVI, GVI, and openness values are aggregated by the average values of the three indicators on SVIs located in that street segment.

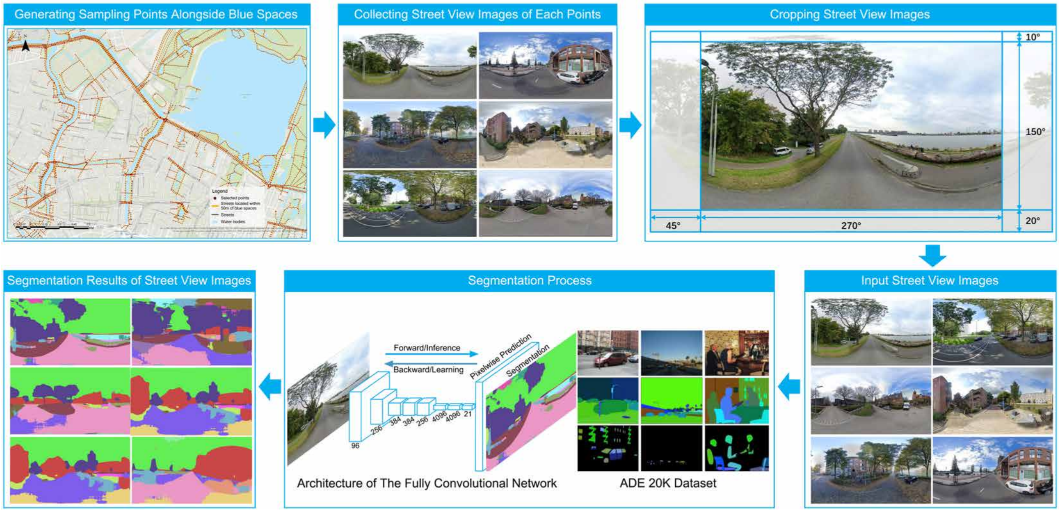


FIG. 6.3 Workflow Measuring Eye-level Spatial Quality Factors of Blue Space.

Spatial quality factors of built environments. Four spatial quality factors related to the built environment are measured in this study, including building density, traffic elements, land-use mix, and visual complexity. Previous studies use different approaches to measure building density, such as floor area ratio (FAR), building area within a specific distance threshold, and building floor height. However, these approaches have led to inconsistent findings regarding the associations between physical activities and building density (Cervero et al., 2009; Huang, Tian et al., 2023; Jiang et al., 2022; Yang et al., 2022). In contrast to the methodologies employed in preceding studies, this study adopts an alternative approach by foregrounding the spatial quality factors that individuals directly perceive. Consequently, building density is quantified by assessing the proportion of building-related features within SVIs, diverging from traditional metrics. Based on a similar calculation process as the other eye-level spatial quality factors, the proportion of the elements related to traffic facilities (e.g. cars, trucks, traffic lights) in SVIs is termed the traffic element factor and incorporated into this research, as prior studies suggest that traffic elements could negatively impact running or cycling (Blitz, 2021; Campos Ferreira et al., 2022; Liu et al., 2023).

Land-use mix (LUM) is another factor that could influence the intensity and frequency of running or cycling. Following Huang, Tian et al.'s (2023) research, this study estimates the value of LUM by the number of different land-use types in the 50m buffer around each street segment. On the other hand, to capture the differences between age groups, distributions of surrounding facilities are included in the analysis, including the count of bus stops, tram stops, sports facilities, cultural facilities, and restaurants/cafes within a 50-metre radius of the corresponding street. The land use data are retrieved from the Dutch Centraal Bureau voor de Statistiek (CBS) (CBS, 2023), while the facility number of the street mainly relies on the point of interest (POI) data available in the OSM database.

Visual complexity influences people's perception of blue space quality and shapes their preferences for running or cycling locations (Zhou et al., 2022). This study operationalises visual complexity as the number of all elements within SVIs and the number of elements occupying more than 5% and 10% of the area of SVIs (Ode et al., 2010).

Spatial quality factors of street connectivity. Street connectivity could influence people's interpretation of street networks and their route choices for running/cycling (Orellana & Guerrero, 2019). Space syntax, which relies on space layouts or properties using topological approaches and graph theory, is commonly employed in current studies to measure street connectivity (Hillier, 2007; Koohsari et al., 2019). Existing studies suggest that the angular analysis indicators calculated by the segment-based model of space syntax have significant explanatory power in predicting cycling and walking behaviours (Law et al., 2014; Moran et al., 2016; Sharmin & Kamruzzaman, 2018). Based on the angular analysis of the segment-based model, this study employs two indicators: angular integration and angular choice. Specifically, angular integration, calculated by the sum of angular change within a certain distance threshold, represents how close each street is to all others. The angular choice shows the degree to which a street segment can be passed through, calculated by the number of times each segment falls on the least angular deviation path between all pairs of segments. The street network on Strava is simplified for analysis, and the integration and choice values for each street segment are calculated in Depthmap X.

6.2.2.3 Neighbourhood Composition Variables: Demographic and Socio-economic Factors

Socio-economic composition variables are obtained at the neighbourhood level (Buurt in Dutch), including urbanicity, non-Western population percentage, and low-income household percentage. Urbanicity is measured by the density of residential populations for each neighbourhood. Highly urbanised areas with dense populations are associated with traffic congestion and discomfort, potentially negatively associated with recreational running or cycling (Rahman et al., 2022). The non-Western population percentage is assessed by the percentage of immigrants whose country of origin is located in Africa, Latin America, or Asia. Prior studies indicate that these immigrants have different preferences for running and cycling than locals (Marquet et al., 2019; Spengler et al., 2011). The low-income household percentage is evaluated based on a fixed purchasing power level after adjusting for annual price developments (6.8% of households at risk of poverty in 2020). The socio-economic information at the neighbourhood level is assigned to each street segment based on the largest overlapping area with the census neighbourhoods. The neighbourhood-level socio-economic data are published openly by CBS and classified by the unique code of neighbourhoods.

6.2.3 Statistical Analysis

The street-level running and cycling counts are estimated by a myriad of spatial quality factors relevant to blue spaces. Four methods, i.e. ordinary least squares (OLS), negative binomial (NB) regression, and spatial lag/error regression, are employed to evaluate the consistency of the results regarding the associations of blue space spatial quality with running and cycling (Figure 6.1). Before fitting the models, the multicollinearity test of independent variables is conducted. The results of variance inflation factors (VIFs) are all below 4.0, indicating no severe multicollinearity problem. Besides, the dependent variables are log-transformed in OLS and spatial regression models due to the heteroskedasticity of the residuals.

To explore the variations in the relationship between two distinct physical activities and spatial quality, OLS models are firstly fitted for straightforward interpretation, that is, how changes in each standardised unit of spatial quality factors are associated with corresponding changes in the counts of running and cycling exercises. Then, NB regression models are constructed to account for the discrete physical activity counts as measured in this study. NB regression is a generalisation of Poisson regression by relaxing its strict assumption that the variance equals the mean. Considering the Poisson-gamma mixture distribution, NB is appropriate to estimate the outcomes when the distribution is over-dispersed (Gardner et al., 1995), which clearly applies to exercise counts at the street level (Figure 6.2). The OLS and NB regression models assume the spatial independence of the dependent variable and residuals. Results from the spatial autocorrelation test, however, show that Moran's I was 0.332 ($p<0.001$) for running and 0.241 ($p<0.001$) for cycling. These figures point to a moderate-to-strong autocorrelation in the counts of physical activity and their error terms among adjacent streets. A disregard for spatial autocorrelation may overestimate the significance of the observed association. For this purpose, the spatial lag and spatial error regression models are finally fitted. Spatial lag regression posits that the value of the dependent variable in certain areas is influenced by its values in the neighbouring areas. Conversely, spatial error regression operates on the premise that the error terms of the dependent variable exhibit correlation across spatial dimensions (Ward & Gleditsch, 2019). Lagrange multiplier tests do not find which assumptions on spatial autocorrelation were preferable. This study, therefore, reports the model results of spatial error regression and compares the results to those of spatial lag regression where appropriate, given that spatial error models perform better in controlling for the inflation of test statistics and in coming to more conservative estimation results (Troy et al., 2016).

To compare the effects of spatial quality on running across different age groups, this study initially applies OLS and spatial regression models, which are consistent with the models mentioned above. However, existing studies have indicated that such model estimates of these correlations might exhibit significant spatial variation, a phenomenon that is particularly pronounced in studies of environmental behaviour (Dong et al., 2023; Huang, Kyttä et al., 2023). Hence, the GWR model is subsequently employed to scrutinise the heterogeneity in the spatial distribution of spatial factors influencing running. In particular, this study integrates multi-age running data to investigate spatial variations in the directional impact of eye-level quality factors across different regions. The GWR model applies a spatial weight function for the areas, employing the Gaussian function as the weight function to determine the optimal bandwidth based on AICc criteria (Tian et al., 2024).

6.3 Results

6.3.1 Descriptive Results and Mapping Analysis

Table 6.1 presents descriptive statistics on recreational running and cycling counts, along with spatial quality factors of blue spaces at the street level. The study area includes 24,050 street segments across 80 neighbourhoods in Rotterdam. This analysis considers ten spatial quality factors with notable variation at the street level, as well as three socio-economic factors representing neighbourhood composition. Figure 6.2 shows that physical activity is concentrated in the northern and central parts of the city, with running more prevalent near the Nieuwe Maas River and Kralingse Lake compared to cycling.

Figure 6.4 [1–4] illustrates the spatial distribution of running by age group. Middle-aged (34–64) and older (65+) runners share similar patterns, with hot-running streets located primarily in the northwest of the Nieuwe Maas River's north bank. As age increases, running activity becomes more concentrated around the Nieuwe Maas River and Kralingen Lake. In contrast, younger runners (18–34) show a more dispersed spatial pattern across the city. Older runners also exhibit higher utilisation of blue spaces outside the city, particularly in the northeast. An overlapping analysis of demographic and income data reveals that while running patterns among the older group align with population and income distributions in some areas, there are regions with relatively few older residents but high running activity among older people (Figure 6.4 [5–6]).

TABLE 6.1 Definitions and Descriptive Statistics of All Variables.

Variable Categories	Variables	Definition	Mean or N	S.D. or %
Physical Activity Counts	Running counts	The recreational running counts by Rotterdam street segment	1483.8	3794.59
	Running counts of 18–34	The recreational running counts by Rotterdam street segment for participants aged 18–34 years	286.52	658.32
	Running counts of 35–54	The recreational running counts by Rotterdam street segment for participants aged 35–54 years	223.45	486.07
	Running counts of 55–64	The recreational running counts by Rotterdam street segment for participants aged 55–64 years	40.07	80.83
	Running counts of 65 plus	The recreational running counts by Rotterdam street segment for participants aged over 65 years	12.15	20.66
	Cycling counts	The recreational cycling counts by the Rotterdam street segment	1579.2	5892.35
Spatial Quality Factors of the Natural Environment	Types of blue space	Nieuwe Maas River	1211	0.05
		Recreational blue spaces	4946	0.21
		Canals, rivers, and other blue spaces	17687	0.74
	Water view index (WVI)	The percentage of bodies of water in view	0.044	0.045
	Green view index (GVI)	The percentage of vegetation in view	0.121	0.091
	Openness	The percentage of the sky in view	0.301	0.126
Spatial Quality Factors of the Built Environment	Building density	The percentage of building elements in view	0.471	0.296
	Land-use mix	The number of different land use types with a 100m buffer	3.08	1.26
	Traffic elements	The percentage of traffic-related facilities in view	0.009	0.013
	Visual complexity	The number of elements in SVIs with multiple thresholds (more than 0%, 5%, 10% area)	4.756	1.757
	Bus stations	The number of bus stations within the 500m buffer	4.92	3.83
	Tram stations	The number of tram stations within the 500m buffer	2.18	3.24
	Sport facilities	The number of sports facilities within the 500m buffer	15.32	25.93
	Cultural areas	The number of cultural facilities within the 500m buffer	0.77	1.91
	Restaurants & cafes	The number of restaurants and cafes within the 500m buffer	6.92	18.02
	Service facilities	The number of community centres within the 500m buffer	0.17	0.44
Spatial Quality Factors of Socio-economic Composition	Urbanicity	The urbanisation level of the neighbourhood, determined by the local ranking rules of Statistics Netherlands	1.59	0.98
	Non-Western population	The percentage of non-Western populations within the neighbourhood	0.30	0.16
	Low-income population	The percentage of the low-income population within the neighbourhood	9.46	5.58

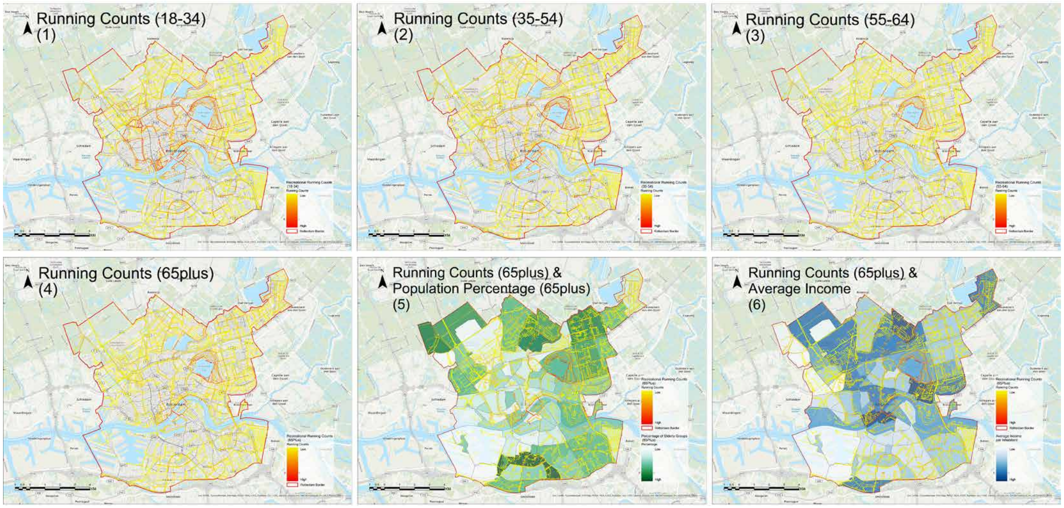


FIG. 6.4 The Spatial Distribution of Recreational Running Among Various Age Groups in Rotterdam.

6.3.2 Model Results

6.3.2.1 Correlations Between Quality Factors and Running/Cycling

Table 6.2 displays standardised regression results, comparing running and cycling activities. The R-squared values increase from Model 1 to Model 4, suggesting enhanced explanatory power for exercise count variance when accounting for statistical distribution (Model 2) and spatial dependence (Models 3 and 4). Proximity to the Nieuwe Maas River correlates with higher running and cycling counts compared to other blue spaces. However, associations differ between exercise types: running shows a positive correlation, while cycling displays a negative one. Notably, WVI negatively correlates with recreational cycling and shows no significant association with running in most models. GVI and openness consistently exhibit positive associations with both activities, with the Nieuwe Maas River vicinity having the most prominent effect sizes among spatial quality factors, except in the NB model for cycling counts. In contrast, openness displays the lowest positive correlations after considering spatial autocorrelation.

TABLE 6.2 Regression Model Results for Recreational Running and Cycling at the Street Segment Level.

	Recreational Running							
	OLS		Negative Binomial		Spatial Lag		Spatial Error	
	S. Coef.	S. E.	S. Coef.	S. E.	S. Coef.	S. E.	S. Coef.	S. E.
Natural environment factors								
Adjacent to inland canals	Reference		Reference		Reference		Reference	
Adjacent to the Nieuwe Maas River	0.980**	0.053	0.909**	0.045	0.631**	0.047	1.080**	0.087
Adjacent to recreational blue spaces	0.080*	0.029	0.043	0.024	0.035	0.026	0.179**	0.044
Water view index (WVI)	-0.018	0.012	0.016	0.010	-0.009	0.011	-0.029*	0.012
Green view index (GVI)	0.155**	0.015	0.158**	0.012	0.142**	0.013	0.222**	0.016
Openness	0.082**	0.017	0.187**	0.014	0.046**	0.014	0.064**	0.015
Built environment factors								
Building density	-0.474**	0.014	-0.592**	0.012	-0.231**	0.013	-0.201**	0.019
Land-use mix	0.376**	0.012	0.308**	0.009	0.234**	0.010	0.271**	0.013
Visual complexity	0.084**	0.014	0.044**	0.011	-0.006	0.011	0.010	0.011
Traffic elements	-0.096**	0.012	-0.256**	0.010	-0.052**	0.011	-0.065**	0.012
Street connectivity factors								
Choice	0.757**	0.012	0.509**	0.010	0.724**	0.011	0.739**	0.011
Integration	0.101**	0.014	-0.094*	0.012	-0.0055	0.012	0.249**	0.020
Socio-economic factors								
Urbanicity	-0.069**	0.015	-0.050**	0.013	-0.012	0.013	-0.042	0.028
Percentage of non-Western population	-0.109**	0.015	-0.248**	0.013	-0.044**	0.013	-0.083**	0.029
Percentage of low-income population	-0.172**	0.015	-0.069**	0.012	-0.093**	0.013	-0.113**	0.030
The lag or error term	–	–	–	–	0.525**	0.007	0.673**	0.007
(Intercept)	5.493**	0.013	6.794**	0.011	2.622**	0.041	5.484**	0.029
Model fit	R-squared	0.314	Pseudo R-squared	0.339	R-squared	0.464	R-squared	0.515

*Note: Standardised regression coefficients and standard errors are reported. * p<0.05, ** p <0.01*

	Recreational Cycling							
	OLS		Negative Binomial		Spatial Lag		Spatial Error	
	S. Coef.	S. E.	S. Coef.	S. E.	S. Coef.	S. E.	S. Coef.	S. E.
	Reference		Reference		Reference		Reference	
	0.470**	0.065	0.248**	0.060	0.379**	0.059	0.646**	0.103
	-0.658**	0.035	-0.782**	0.033	-0.367**	0.032	-0.410**	0.053
	-0.082**	0.015	-0.036*	0.015	-0.056**	0.014	-0.065**	0.015
	0.056*	0.018	0.292**	0.017	0.071**	0.017	0.115**	0.020
	0.091**	0.021	0.429**	0.019	0.049**	0.017	0.048*	0.020
	-0.126**	0.017	-0.116**	0.016	-0.051**	0.016	-0.044*	0.023
	0.509**	0.014	0.668**	0.013	0.321**	0.013	0.368**	0.016
	0.063**	0.017	0.018	0.015	0.039**	0.013	0.039**	0.014
	-0.116**	0.015	-0.332**	0.014	-0.069**	0.013	-0.076**	0.015
	0.988**	0.015	0.361**	0.014	0.936**	0.014	0.923**	0.014
	0.278**	0.017	-0.012	0.016	0.108**	0.016	0.450**	0.025
	-0.142**	0.019	-0.263**	0.017	-0.095**	0.017	-0.242**	0.032
	-0.057*	0.018	-0.016	0.017	-0.025	0.017	-0.007	0.033
	-0.132**	0.018	-0.110**	0.017	-0.084**	0.016	-0.109**	0.034
	–	–	–	–	0.476**	0.008	0.602**	0.008
	4.748**	0.016	7.014**	0.015	2.505**	0.040	4.728**	0.319
	R-squared	0.311	Pseudo R-squared	0.328	R-squared	0.476	R-squared	0.457

Building density and traffic elements negatively correlate with both activities, whereas land-use mix shows a positive association. Visual complexity correlates positively with cycling but not with running until visual complexity thresholds are adjusted in the sensitivity analysis, revealing a significant positive relationship with running (Table 6.3).

Street connectivity, particularly the choice factor, strongly predicts both running and cycling counts, with the integration factor showing a somewhat negligible positive correlation. Unlike other spatial quality factors, integration coefficients significantly increase after accounting for spatial autocorrelation in Models 3 and 4.

Urbanicity levels negatively impact cycling, discouraging this activity in denser areas, while its association with running remains insignificant after controlling for spatial effects. The non-Western population percentage negatively correlates with running and shows no significant correlation with cycling, and similar negative correlations are observed between low-income percentages and both types of activities across models.

TABLE 6.3 Sensitivity Analysis: Visual Complexity.

	Cycling				Running			
	Spatial Lag		Spatial Error		Spatial Lag		Spatial Error	
	S. Coef.	S. E.	S. Coef.	S. E.	S. Coef.	S. E.	S. Coef.	S. E.
Visual complexity	0.039**	0.013	0.039**	0.014	-0.006	0.010	0.010	0.011
Visual complexity (5%)	0.052**	0.015	0.047*	0.016	0.095**	0.012	0.072**	0.012
Visual complexity (10%)	0.068**	0.015	0.070**	0.016	0.070**	0.012	0.059**	0.012

*Note: Standardised regression coefficients and standard errors are reported. * p<0.05, ** p <0.01*

6.3.2.2 Correlations Between Quality Factors and Running Among Different Age Groups

Table 6.4 assesses the impact of spatial quality factors on running across different age groups using three regression models. Natural factors connected to blue space show consistent negative correlations between WVI and running for all age groups, with more substantial impacts observed among the young (18–34) and middle-aged (35–54). GVI positively correlates with running across all models and age groups, though its influence diminishes with age. Openness significantly enhances running, especially among individuals aged 35 to 54.

Regarding built environment factors, building density negatively correlates with running across all demographic groups, with reduced effects on older people. Traffic elements adversely impact running in all models. Visual complexity positively correlates with running only in the 18–34 age group, with controlled spatial effects. The positive influence of land-use mix on running decreases with age.

Similar to GVI and LUM, the choice value of street segments positively correlates with running but weakens with age. Conversely, street integration value shows inconsistent results, with positive effects only in the 18–34 age group when considering spatial effects. Public facilities also influence running; for example, bus stations negatively correlate with running across all groups, intensifying with age. Sports facilities positively impact running in all groups, with more robust effects in younger cohorts. Service facilities exhibit a slight negative association with running counts in models controlling for spatial effects. The results for tram stations, restaurants, and cafes show less consistency.

TABLE 6.4 Regression Results for Recreational Running Among Different Age Groups.

Regression Model Results (Recreational Running)						
	18–34 (S. Coef.)			35–54 (S. Coef.)		
	OLS	SLM	SEM	OLS	SLM	SEM
Natural environment factors						
Water view index	-0.021	-0.022*	-0.046**	-0.050**	-0.033**	-0.047**
Green view index	0.114**	0.099**	0.171**	0.141**	0.112**	0.167**
Openness	0.055**	0.031*	0.033*	0.067**	0.044**	0.037**
Built environment factors						
Building density	-0.595**	-0.239**	-0.314**	-0.364**	-0.158**	-0.180**
Land-use mix	0.376**	0.171**	0.311**	0.353**	0.175**	0.297**
Visual complexity	0.070**	0.040**	0.005	0.041*	0.021	-0.014
Traffic elements	-0.104**	-0.072**	-0.087**	-0.108**	-0.077**	-0.089**
Bus stations	-0.023	-0.029*	-0.088**	-0.044**	-0.039**	-0.102**
Tram stations	0.122**	0.033*	0.093*	-0.007	-0.018	-0.041
Sport facilities	0.237**	0.123**	0.324**	0.197**	0.113**	0.258**
Cultural areas	0.160**	0.084**	0.219**	0.164**	0.091**	0.192**
Restaurants & cafes	-0.021	-0.004	-0.079	-0.024	-0.015	-0.042
Service facilities	-0.064**	-0.028*	-0.031	-0.067**	-0.032**	-0.058**
Street connectivity factors						
Choice value	0.706**	0.678**	0.678**	0.737**	0.694**	0.691**
Integration value	0.256**	0.074**	0.360**	0.043*	-0.012	0.254**
Socio-economic factors						
Urbanicity	0.026	0.036*	-0.007	0.033*	0.040**	0.049
Non-Western population	-0.156**	-0.052**	-0.103**	-0.089**	-0.030*	-0.027
Low-income population	-0.030	-0.016	-0.049	-0.125**	-0.061**	-0.124**
(Intercept)	3.823**	1.597**	3.848**	3.984**	1.851**	4.009**
LAMBDA			0.688**			0.667**
Adj. R2	0.411	0.567	0.599	0.342	0.488	0.532

*Note: Standardised regression coefficients and standard errors are reported. * p<0.05, ** p <0.01*

	55–64 (S. Coef.)			65 plus (S. Coef.)		
	OLS	SLM	SEM	OLS	SLM	SEM
	-0.036**	-0.024*	-0.033**	-0.035**	-0.026**	-0.035**
	0.133**	0.105**	0.157**	0.117**	0.084**	0.116**
	0.051**	0.039**	0.038**	0.038**	0.029**	0.029**
	-0.183**	-0.075**	-0.098**	-0.136**	-0.062**	-0.092**
	0.308**	0.151**	0.272**	0.207**	0.100**	0.186**
	0.026	0.013	-0.018	0.026*	0..019	0.000
	-0.099**	-0.070**	-0.080**	-0.082**	-0.059**	-0.068**
	-0.118**	-0.068**	-0.144**	-0.127**	-0.066**	-0.140**
	-0.005	-0.015	-0.048	-0.009	-0.015	-0.047*
	0.195**	0.105**	0.240**	0.146**	0.077**	0.183**
	0.115**	0.062**	0.125**	0.110**	0.056**	0.115**
	0.066**	0.037*	0.024	0.023	0.014	-0.021
	0.036**	-0.017	-0.052*	-0.015	-0.007	-0.029
	0.606**	0.570**	0.571**	0.460**	0.425**	0.428**
	0.010	-0.026*	0.166**	-0.079**	-0.059**	0.071**
	-0.116**	-0.039**	-0.067*	-0.161**	-0.063**	-0.104**
	-0.064**	-0.022	0.020	-0.037**	-0.011	0.004
	-0.169**	-0.077**	-0.136**	-0.184**	-0.084**	-0.156**
	2.447**	1.097**	2.478**	1.578**	0.703**	1.600**
			0.644**			0.621**
	0.284	0.439	0.471	0.219	0.377	0.399

6.3.2.3 GWR Results: Eye-level Quality Factors Impacting Running Among Age Groups

Figure 6.5 illustrates the main findings from the GWR model analysis of eye-level factors at each street segment, categorised and visualised using the Jenks Natural Breaks method. The results reveal two significant dimensions: the spatial size and shape of bodies of water, which notably influence running in urban areas. Notably, positive effects of the WVI are concentrated around large-scale bodies of water, while negative effects are clustered near smaller, linear blue spaces. The positive impact of the GVI diminishes with increasing distance from the city centre, and negative effects of openness tend to occur near minor or linear blue spaces in Rotterdam's eastern and western regions.

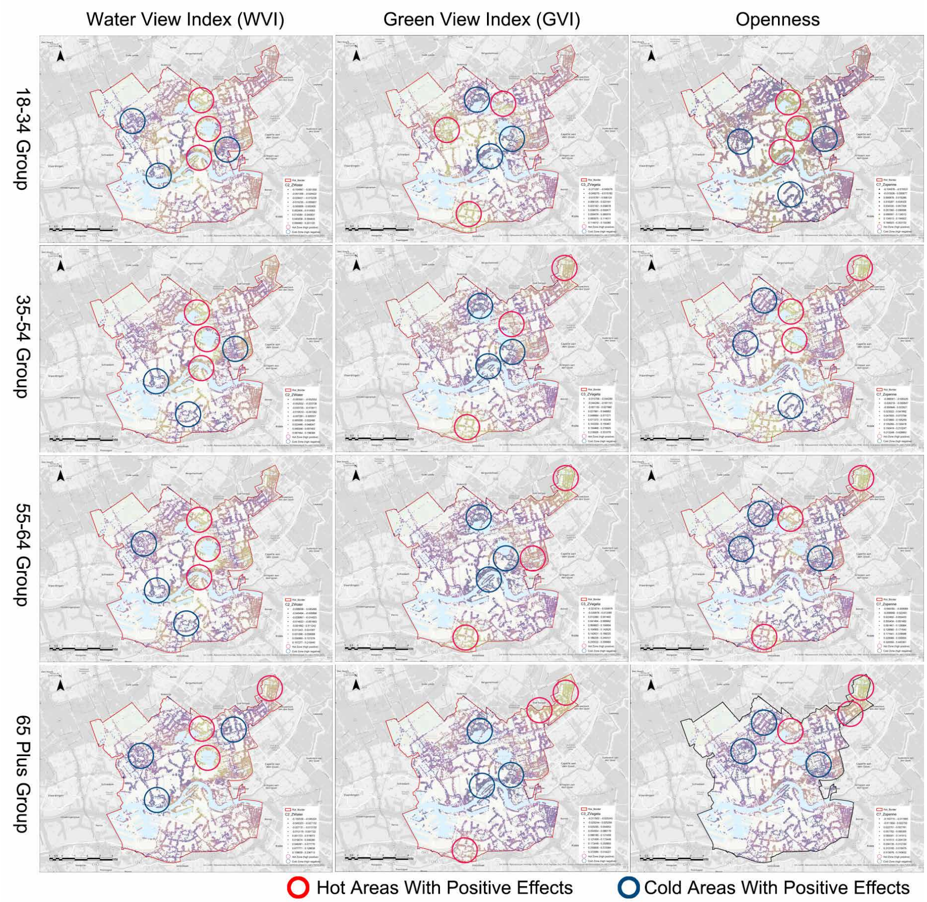


FIG. 6.5 Key Results of the GWR Model Analysis.

Additionally, the GWR analysis indicates that the influence of eye-level factors on running varies by age group. For the younger group (18–34), positive effects of the WVI cluster along the Nieuwe Maas River, unlike the older group (65+), where the Nesselande district becomes a focal area. In contrast, while western Rotterdam shows positive GVI effects on running for the 18–34 age group, these effects are predominantly negative for other age groups. In Nesselande, GVI impacts may shift from positive for the middle-aged and older groups to negative for the younger group. Differences in sensitivity to openness across age groups also emerge, showing inconsistent results near the city's central lakes, the Nieuwe Maas River, and the Nesselande district. Comprehensive GWR model results are included in the Appendix B.

6.4 Interpreting the Results

6.4.1 The Impact of Quality Factors on Running and Cycling

Different blue spaces encourage various physical activities. Paths along the Nieuwe Maas River are popular for both running and cycling, while smaller bodies of water favour running, and inland waterways are preferred for cycling. This finding aligns with previous studies showing that large blue spaces attract runners and cyclists for their restorative benefits (Murrin et al., 2023; Pasanen et al., 2019; Völker & Kistemann, 2013). Well-designed facilities in recreational blue spaces support running but may interrupt cycling continuity. Notably, eye-level water views do not increase physical activity, possibly due to challenging wind speeds at water edges (Pasanen et al., 2019). The study confirms that, like green spaces, eye-level vegetation in blue spaces promotes running and cycling (Chen et al., 2020; Huang et al., 2022; Ki & Lee, 2021; Lu et al., 2019; Nawrath et al., 2019). Additionally, openness enhances these activities, offering insights for designing appealing and comfortable public spaces (Dai et al., 2021; Ma et al., 2021).

Building density negatively impacts running and cycling, with more substantial effects on running due to the higher visibility of building elements that can overwhelm runners but not cyclists, who travel faster and are less affected. Cycling shows a weaker negative correlation, possibly because bike lanes are typically farther from buildings. Visual complexity, although enhancing cycling appeal due to aesthetic preferences, does not significantly impact running unless specific thresholds are met. The relationship between visual complexity and aesthetic response is inverted U-shaped, suggesting that moderate complexity is optimal for enhancing enjoyment without overwhelming exercisers (Berlyne, 1970; Palmer et al., 2013).

Land-use mix significantly influences running and cycling in blue spaces, with a more pronounced effect on cycling, likely due to the Netherlands' robust cycling infrastructure amidst diverse amenities (Christian et al., 2011; Huang, Tian et al., 2023; Kerr et al., 2016; Stronegger et al., 2010; Xiao et al., 2022). Traffic elements, including cars and traffic lights, limit both activities, reflecting concerns over safety and aesthetic disruption of the environment (Liu et al., 2023). Choice and integration strongly correlate with both running and cycling, with the choice factor being the most influential, especially for cycling. This finding suggests that cyclists prioritise route selection over natural surroundings (Koohsari et al., 2016; Orellana & Guerrero, 2019; Sharmin & Kamruzzaman, 2018). The choice factor relates to a street's likelihood of being used for transit, while integration pertains to its potential as a destination, making choice a better predictor for the discretionary nature of running and cycling (Turner, 2007; Yamu et al., 2021).

Neighbourhood socio-economic compositions significantly influence physical activities in blue spaces. Urbanicity negatively affects cycling but positively affects running, indicating that cycling is favoured in less populated areas while running is more common in denser regions. The concept of 'eyes on the street' suggests that public presence enhances safety and social cohesion, which is particularly important for running, especially among socio-economically disadvantaged groups (Jacobs, 1961; Troy et al., 2016). Furthermore, areas with a high non-Western population percentage show less running activity and neighbourhoods with many low-income households see reduced cycling and running. Affluent areas generally provide better-quality blue spaces conducive to physical activity and have residents who are more engaged in maintaining health (Huang, Tian et al., 2023; Troy et al., 2016).

6.4.2 Spatial Distributions and Features of Running Among Different Age Groups

This analysis highlights the distinct attractiveness of blue spaces for running. The northern bank of the Nieuwe Maas River is notably popular, with riverfronts known for attracting physical activity (Boakye et al., 2021; Gascon et al., 2017; Vert, Carrasco-Turigas, et al., 2019; Völker & Kistemann, 2015). Despite their denser populations, central urban areas show higher running activity than peri-urban areas, likely due to better facilities and organised environments. Key locations such as the streets along the Nieuwe Maas River and Kralingen Lake attract runners of all ages, demonstrating the broader appeal of large blue spaces (Pasanen et al., 2019; Völker & Kistemann, 2013, 2015).

The mapping analysis also reveals that preferences for running locations vary by age. Older adults tend to run in more familiar, socially connected, and accessible locations near blue spaces, reflecting increased place attachment and reduced mobility. In contrast, older people prefer running in quieter blue spaces outside the city centre, possibly due to higher income flexibility and a desire for less crowded environments (Dean et al., 2020; Grow et al., 2008; Wang et al., 2016). These insights can inform urban planning strategies to enhance and evenly distribute blue spaces, particularly at the city's fringes, to improve running opportunities for all ages.

6.4.3 The Attractiveness of Quality Factors for Running Among Different Age Groups

The analysis highlights how the visual impact of water on running varies by the size and shape of bodies of water and across age groups. More specifically, WVI positively influences running around large bodies of water but can discourage running in smaller, linear spaces. This effect also differs between young adults (18–34) and older people (65+), particularly around the Nieuwe Maas River and in the Nesselande district. Spatial regression reveals that WVI's negative association with running intensity persists across all ages, with its impact lessening with age. This finding may be due to the varying nature of bodies of water and safety concerns, especially among older people (Garrett et al., 2019; Nutsford et al., 2016; White et al., 2020). Additionally, eye-level greenness generally promotes running among all age groups, though its positive effect decreases with age, as older runners prioritise comfort, sociality, and safety over visual greenery (Levy-Storms et al., 2018; Sugiyama & Ward Thompson, 2007). Views of buildings and traffic also negatively impact running for all ages, with this correlation diminishing as runners age, possibly reflecting older adults' greater adaptability to public spaces (Huang, Tian, et al., 2023; Jiang et al., 2022; Puhakka et al., 2015; A. Zhang et al., 2022).

The spatial correlation analysis shows that younger runners (18–34) are uniquely attracted to blue spaces with high visual complexity, driven by their curiosity and responsiveness to visual stimuli in urban environments (Camp et al., 1984; Tapiro et al., 2020). However, older individuals may avoid these areas due to perceived safety

TOC

concerns (Ottoni et al., 2021). Additionally, well-organised road networks and diverse land use significantly enhance running appeal, especially for younger people who prioritise these elements for longer, more physically demanding routes (Burton et al., 2012). Differences in preferences also emerge regarding facilities; younger runners favour blue spaces near sports and cultural facilities, aligning with their interest in combining several recreational activities. In contrast, bus stops negatively affect running for older individuals due to their interference with routes and safety concerns (Ottoni et al., 2021). Meanwhile, the presence of restaurants and cafes shows no significant impact on running across age groups, likely because these locations are more frequented during less strenuous activities like walking (Kim, 2015).

6.5 Translating Evidence into Design Knowledge

The research findings provide urban practitioners, including planners, designers, and policymakers, with some references and evidence for developing tailored design knowledge, effectively harnessing the health benefits of blue spaces.

6.5.1 Design Knowledge Translation Based on Comparisons Between Running and Cycling

First, the planning of the running and cycling route network should align with the specific features of blue space types, such as (1) organising cycling and running routes around emblematic blue spaces featuring large bodies of water; (2) coordinating running routes in conjunction with other recreational purposes in blue spaces; and (3) designing cycling routes in harmony with linear blue spaces (Figure 6.6 [a–c]). Notably, street greenery is critical to recreational running and cycling. More vegetation should be introduced into blue space design, especially when designing cycling and running routes (Figure 6.6 [d]). Integrating greenery into blue space could provide additional ecosystem services and benefits as well (e.g. ecological values, energy savings, and cooling effects; Brunner & Cozens, 2013).

However, compared to the top-down measure of greenness, more attention should be paid to eye-level greenery exposure in spatial design due to its direct connection with individuals' field of vision and consequent use of spaces. Furthermore, expanding the visual openness of blue spaces would bring a safer spatial perception and increase their use. However, it is crucial to balance the trade-offs of increasing greenery and visual openness in blue space design, such as by incorporating strategies using bushes or limited canopy size to maintain openness (Figure 6.6 [e]).

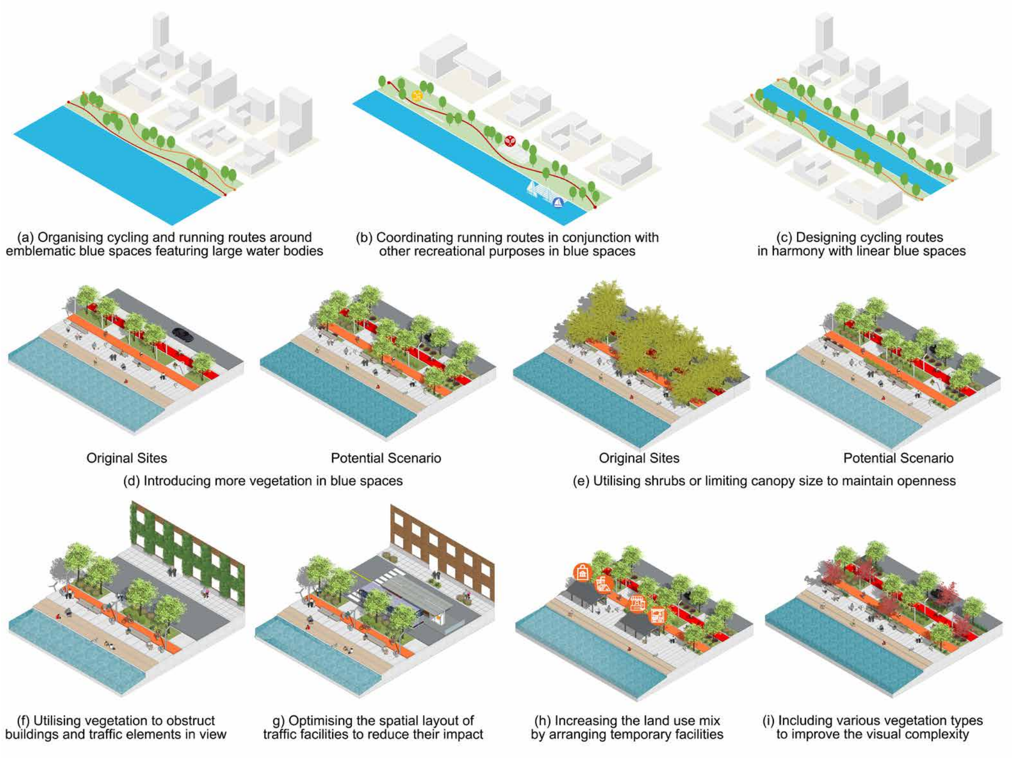


FIG. 6.6 Examples of Spatial Patterns for Blue Space Design.

Second, higher building density and more traffic elements in view are associated with less exercise, particularly less running. To design exercise-supportive blue spaces, urban planners and policymakers should control the number and layout of buildings and traffic elements around blue spaces or make full use of vegetation to obstruct buildings and traffic elements in view, such as vertical greening (Figure 6.6 [f-g]). Running and cycling increase with a more diverse land-use mix, posing a challenge for improving diversity while reducing building density. Potential strategies include providing more temporary public facilities or integrating these facilities with vegetation to minimise the negative impact of high building density (Figure 6.6 [h]). Moreover, the research results suggest that maintaining an intermediate level of visual complexity in blue spaces could stimulate the individual's curiosity and desire for exploration, thus promoting running and cycling. Incorporating diverse landscape elements, such as various vegetation types and well-designed public facilities, could be a viable approach for designers to enhance the visual complexity of blue spaces (Figure 6.6 [i]).

Third, street connectivity reflects the possibility of choosing different routes. Although the results show that street connectivity is significantly associated with physical activities in blue spaces, the spatial interventions required to adjust street networks are always laborious and time-consuming. A potential strategy for optimising the street network involves utilising the highly connected streets adjacent to blue spaces as the street network skeleton and enhancing the spatial quality surrounding them to promote physical activity and harness the health benefits of blue spaces.

Fourth, physical activity also shows spatial distribution patterns based on the socio-economic composition of the neighbourhoods. The potential challenge lies in the limited availability and poor maintenance of running and cycling facilities in neighbourhoods with a concentration of non-Western groups and low-income people. Planners and policymakers should prioritise the equitable distribution of high-quality blue spaces, particularly in these neighbourhoods. Additionally, running and cycling behaviours vary in need and preference among areas of different population densities. For example, blue spaces in highly populated areas should place running facilities in and connect the route with existing networks, emphasising the interaction with other public facilities and improving accessibility to surrounding neighbourhoods. In contrast, more cycling-related facilities could be arranged in less urbanised blue spaces.

Finally, planners and policymakers should consider the synergies and trade-offs among the above strategies. For instance, when designing blue spaces for running, the LUM can be improved by creating mixed land use functions while contributing to the urbanicity to attract more eyes to the street. In contrast, blue spaces with good street connectivity tend to have a higher building density in view; therefore, it is necessary to balance these two factors in practice or implement other patterns to mediate the adverse effects, such as the aforementioned vertical greening.

6.5.2 Design Knowledge Translation Based on Comparisons Among Various Age Groups

In addition to translating evidence from comparisons between two types of physical activities, the insights derived from various age groups can also be invaluable for crafting tailored design knowledge. Initially, the analysis indicates that different age groups appreciate similar qualities in blue spaces conducive to running. For instance, practitioners are advised to enhance the diversity of greenery and reduce the visibility of buildings and traffic-related elements at eye level, as supported by the analysis of the two activities previously mentioned. However, considering the notable disparities among various age groups, spatial interventions should be thoughtfully tailored regarding running, with particular emphasis on vulnerable groups like older people. For example, integrating diverse vegetation and landscape elements and combining blue spaces with cultural and sports facilities could stimulate enthusiasm for running among younger individuals. Conversely, for older adults, aspects such as convenience and safety perception in blue spaces significantly influence their propensity to engage in running.

Moreover, building on spatial heterogeneity analysis, future spatial interventions and policy formulations should consider blue space and neighbourhood-specific differences to enhance running opportunities. Specifically, the analysis suggests that ensuring water visibility in large-scale blue spaces could encourage running. Conversely, in smaller-scale blue spaces, the integration of vegetation and cultural/sport facilities should be employed to create a vibrant atmosphere that entices individuals to run. At the city level, planners and policymakers should focus on enhancing the environmental quality of blue spaces in economically affluent neighbourhoods to maximise health benefits. Simultaneously, attention should be directed toward blue spaces in less affluent neighbourhoods, recognising their potential to contribute to health improvements and drive socio-spatial (re) development, especially by attracting residents who prioritise individual health.

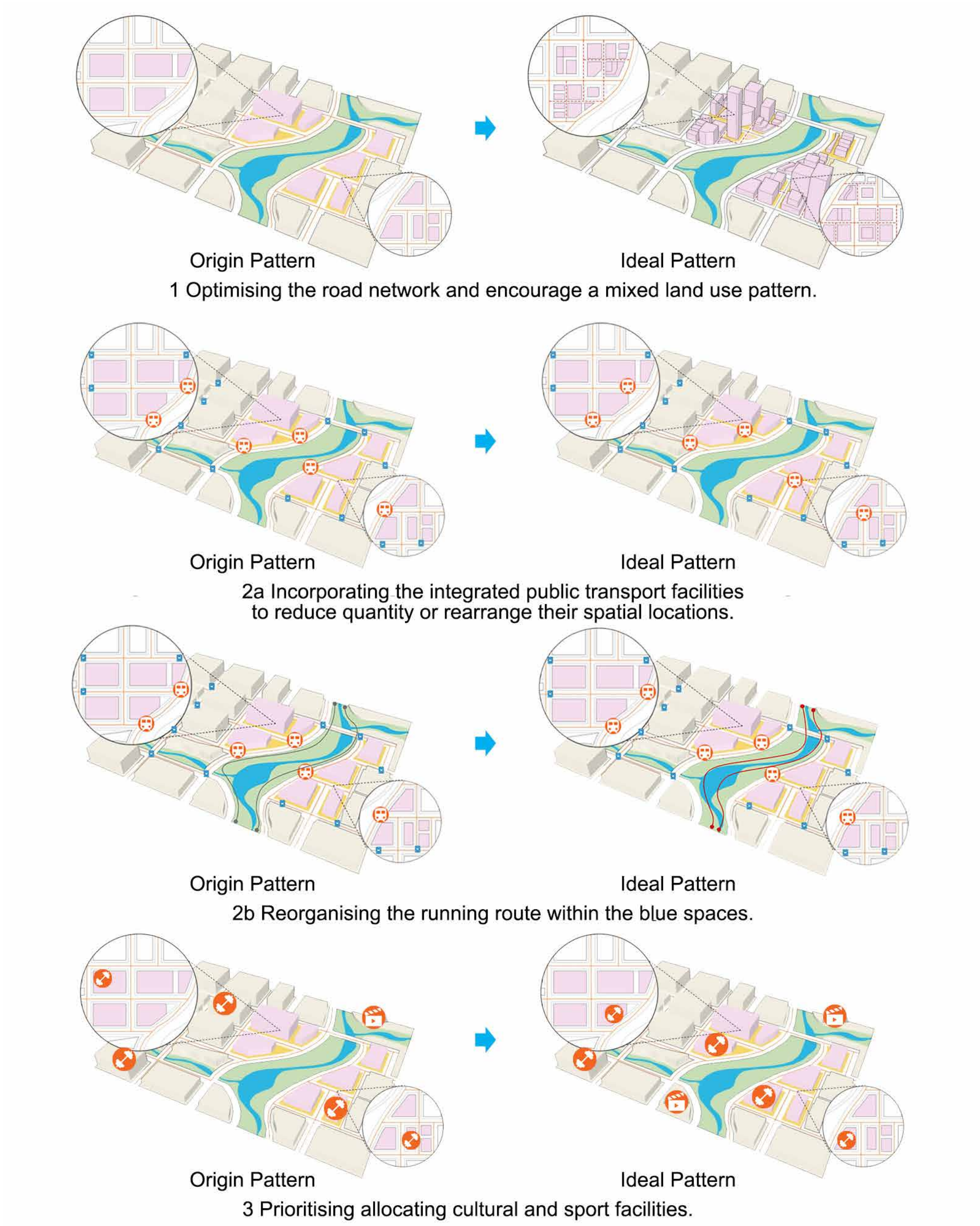


FIG. 6.7 The Design Principles and Spatial Patterns for Running-friendly Blue Space at the Regional/District Level.

Figure 6.7 illustrates several examples of regional/district-level design principles and spatial patterns that have been derived from the evidence above, encompassing (1) the optimisation of road networks and promotion of mixed land use patterns, (2) enhancement of the spatial layout of public transport facilities or running routes, and (3) integration of cultural and sports facilities with blue spaces. Additionally, Figure 6.8 delineates several design principles and spatial patterns at the individual level for running-friendly blue spaces according to the results. Specifically, it recommends (1) increasing eye-level greenery and visual complexity in blue spaces, using a multi-layered configuration of vegetation, while emphasising regular vegetation planting in blue spaces frequently used by older people to reduce perceptions of a lack of safety (Figure 6.8 [a]); (2) limiting the proportion of building elements in blue spaces through various forms of vegetation, including trees in the streets and vertical greening (Figure 6.8 [b]); (3) optimising the spatial arrangement of public facilities to minimise interference with running activities, such as on-land facilities, bus stops, and other traffic-related elements (Figure 6.8 [c-d]).

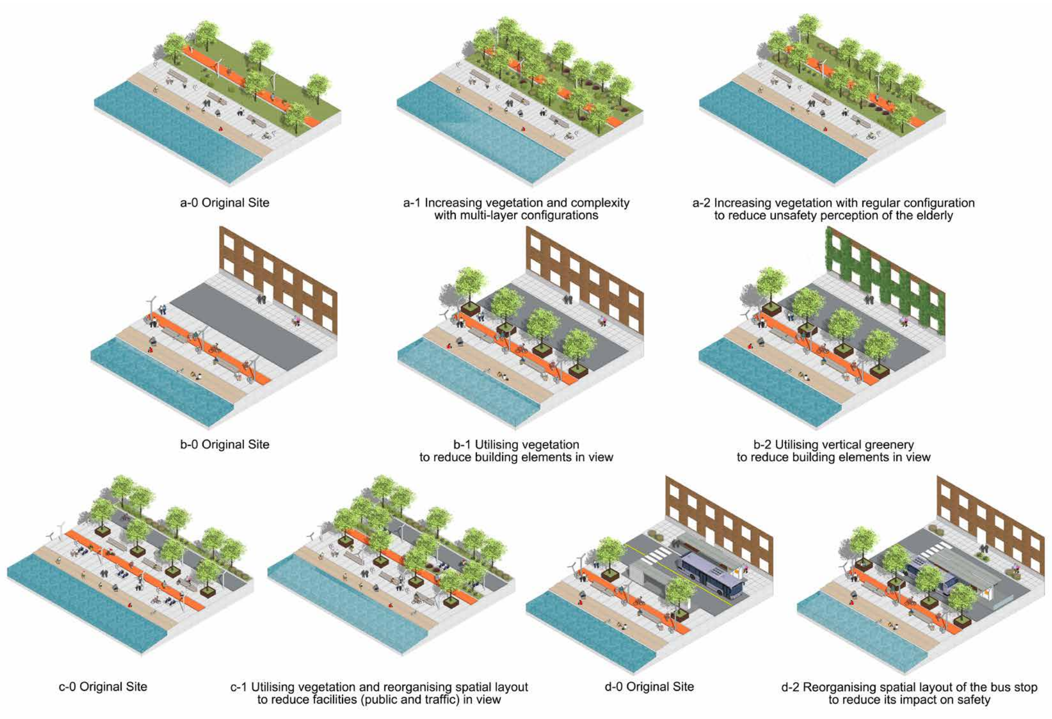


FIG. 6.8 The Design Principles and Spatial Patterns for Running-friendly Blue Spaces at the Local Level.

6.6 Strengths and Limitations

This study is one of the first studies to assess the associations between the spatial quality of blue spaces and physical activity in a high-density urban environment. The study integrates multi-source data (e.g. SVI and POI data) to identify the nuanced spatial quality of blue spaces, together with a GPS-based VGI approach to measure street-level physical activities. Adopting interdisciplinary approaches and selecting diverse measures prioritise people's perceptions and preferences regarding spatial quality and reduce the bias from self-reported data. Particularly, the eye-level element proportions through SVIs and deep-learning techniques are more representative of people's activity in reality than top-down measurement relying on land use data. Moreover, several statistical models are used in this study to control for the distributional characteristics, spatial autocorrelation, and spatial heterogeneity of the research outcome, i.e. recreational running and cycling counts. Last but not least, utilising the knowledge/evidence-based design paradigm, this chapter proposes practical knowledge for designing exercise-supportive and health-promoting blue spaces from the perspective of spatial quality.

This study also has some limitations. First, due to the lack of information at the individual level (such as individuals' demographic information and their personal running records), this study cannot investigate how closely the Strava users can represent the city's general population. The reliability and representativeness of the Strava data could be examined and verified in future studies by incorporating field observations or audits of public space usage. Second, although this study specifies the spatial quality of blue space using crowdsourced data, there remain some aspects of blue spaces that have not been considered, such as changes in spatial quality factors with time (e.g. changes between different seasons, weather, days vs nights), and the configurational features of elements in view rather than the composition characteristics used in the current study. Third, the optimisation potential of the analysis deserves further attention. Some emerging methods, such as generalised additive models that examine nonlinear relationships and emerging machine learning-based models (e.g. random forest regression), may have greater explanatory power and higher accuracy in predicting the occurrence of physical activity. Fourth, future explorations should focus on more comprehensive evidence collection and the development of design knowledge concerning spatial quality. The design knowledge generated in this chapter primarily addresses the health-promoting pathway of blue space in relation to improving physical activity, which is insufficient. Future efforts should focus on collecting and translating evidence on other health-promoting pathways, such as determining which quality factors of blue spaces offer more significant psychological benefits or foster environments that increase social interaction.

6.7 Conclusion

Integrating crowdsourced data from VGI and SVIs, this chapter explored the relationship between the spatial quality of blue spaces and the level of running/cycling in Rotterdam, the Netherlands. The analysis of two types of physical activity shows that factors like the green view index, visual openness, land-use mix, and street connectivity consistently affect both activities, though their impact levels vary. Other factors, such as urbanisation and spatial complexity, show mixed effects. Age-specific analyses reveal that running in blue spaces varies by age, with notable differences and spatial heterogeneity in how spatial quality factors affect running activities across age groups.

Based on these insights, tailored design principles and spatial patterns were proposed, considering the varied environmental needs of different activities and age groups. These findings enhance understanding of the blue-health mechanism and provide practical guidance for designing healthy blue spaces. The comprehensive details of the design knowledge are delineated in the Appendix A, formatted as a separate booklet, which complements the design knowledge discussed in the preceding two chapters.

PART III Application, Discussion, and Outlook

This part focuses on the final phase of the framework, which entails verifying the feasibility and effectiveness of the proposed design knowledge through design experiments and expert interviews, as well as reflecting on the current research outcomes and discussing future directions for blue-health research. Specifically, Chapter 7 conducts design experimentation through workshops with master's students and PhD candidates to validate the effectiveness of the proposed design principles and spatial patterns. Next, Chapter 8 engages six experts from diverse disciplines to discuss the practical potential of the current research outcomes and contemplate the prospects for future research. Chapter 9 concludes the study, summarising the main findings, reflecting on potential limitations, and providing an outlook for future directions.

7 Applications of Practical Design Knowledge in a Design Workshop

This chapter addresses research question 3: What is the potential of applying practical design knowledge in freshwater blue space design and planning processes? Consequently, it evaluates the design knowledge through a simulated design project, demonstrating its application potential in future practices. A design workshop was conducted in Delft on May 29, 2024, involving an international ensemble of master's students and PhD candidates primarily from disciplines related to spatial design, including urbanism, landscape architecture, urban studies, and architectural design. Section 7.2 delineates the methodology of the design workshop, elucidating the information on design instruments, criteria for participant selection, the configuration of the workshop, and the methods employed for data collection and analysis. Section 7.3 presents a detailed description, analysis, and evaluation of the results gathered during and after the workshop. Finally, Section 7.4 discusses the insights and refinements made to the design knowledge following the workshop evaluation and contemplates the methodological challenges faced throughout the research process.

TOC

7.1 Introduction

In landscape architecture and related disciplines, spatial design is a crucial activity that develops solutions for urban and rural environments, aiming to foster spatial, ecological, and social development (Nijhuis & de Vries, 2019). In other words, spatial design entails the construction and articulation of spaces, culminating in architectonic compositions that seamlessly integrate form with multi-objective requirements (Liu, 2020). Traditionally, spatial design has been viewed as a ‘black box’, where designers amalgamate their experience with site-specific information to develop solutions that address many objectives. With advancements in understanding the design process and the development of the knowledge/evidence-based design paradigm, spatial design has been acknowledged as a form of research and conceptualised into three interconnected processes: analysis, synthesis, and evaluation (Jones, 1992; Nijhuis & de Vries, 2019). The practical tools and knowledge that assist practitioners in these processes are collectively termed design knowledge.

Historically, several famous studies have focused on summarising and developing design knowledge, including the well-known five points of new architecture (Corbusier, 1986) and pattern language (Alexander, 1977). The practicality and effectiveness of these famous endeavours have been validated across various applications. As outlined in Part I, this study introduces a methodological framework designed to translate health-promoting evidence of blue spaces into practical design knowledge. This process includes the development of design principles, spatial patterns, and evaluation methods aimed at creating healthy and sustainable urban environments. Part II concentrated on developing design knowledge across various design themes, with the developed design knowledge meticulously compiled and presented in the Appendix A as a distinct booklet. However, the practical potential of the design knowledge developed in this study has not yet been verified compared to the widely recognised and utilised design knowledge in the field. Although deriving some design knowledge from precedent cases might address concerns regarding its application potential to some extent, a direct method to test its usability and effectiveness is needed.

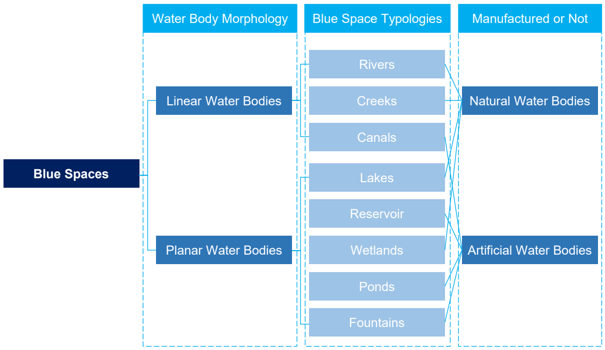
7.2 Data and Methods

7.2.1 Design Objective and Instruments of the Workshop

In design, practical knowledge functions as an essential instrument for practitioners. It is distilled from context-specific situations and presented as generic, adaptable knowledge (Nijhuis & de Vries, 2019). This approach enables practitioners to apply it flexibly to various sites, thereby effectively achieving design goals and addressing site-specific challenges. In Part II, the research incorporated a global precedent analysis along with in-depth site explorations in Rotterdam to develop design knowledge based on four primary design themes aimed at harnessing the health benefits of blue space. As mentioned above, this knowledge is compiled into a distinct booklet, regarded as a reference tool for practitioners. Consequently, this booklet served as the principal instrument used by participants in the workshop.

Given the extensive content within the booklet, it is impractical to test all the design knowledge during the limited duration of a workshop. Consequently, this study has selected a subset of the design knowledge as a representative sample, allowing for the observation, evaluation, and reflection on its overall practicability. After considering the scale of the test site, the workshop incorporates local-level design knowledge aimed at enhancing the quantity, accessibility, and visibility of blue spaces (Figure 7.1). Accordingly, to ensure clarity and facilitate participant understanding, the design objective for the testing sites is explicitly defined: to enhance the public visibility and accessibility of the blue spaces of the sites.

ALL DESIGN PRINCIPLES AND SPATIAL PATTERNS FOR QUANTITY



DESIGN PRINCIPLES AND SPATIAL PATTERNS FOR ACCESSIBILITY AT THE LOCAL LEVEL

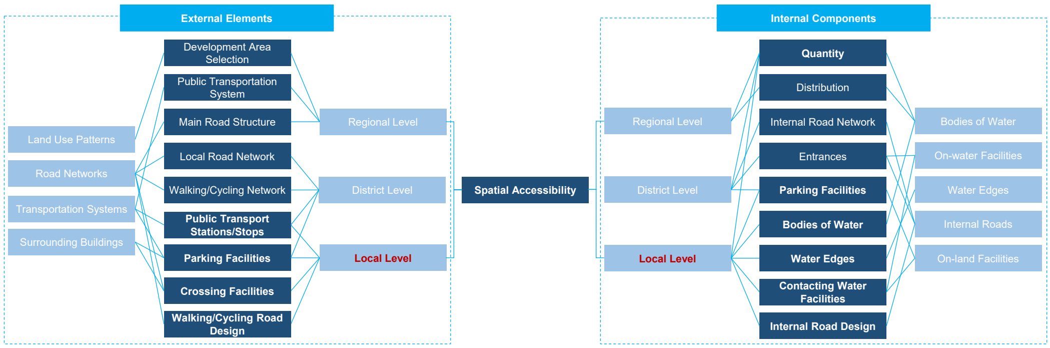
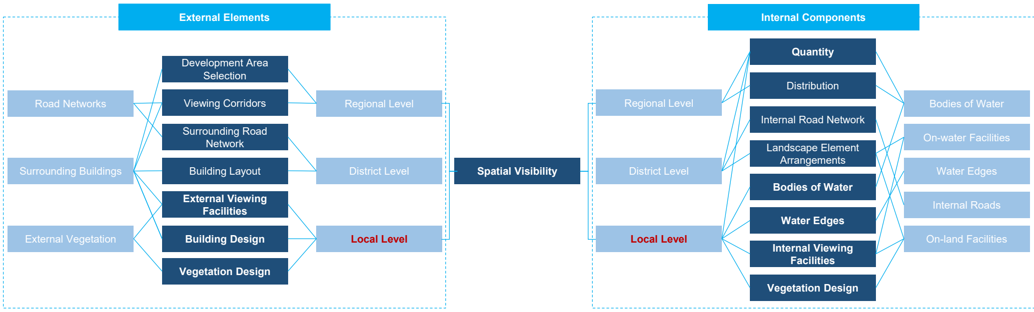


FIG. 7.1 The Selected Knowledge for the Design Workshop.

TOC

DESIGN PRINCIPLES AND SPATIAL PATTERNS FOR VISIBILITY AT THE LOCAL LEVEL



EXAMPLES OF DESIGN PRINCIPLES AND SPATIAL PATTERNS IN THE BOOKLET

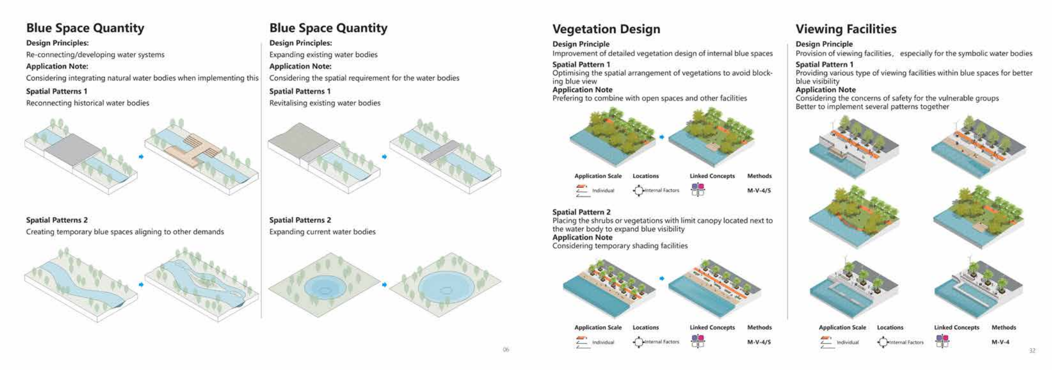


FIG. 7.1 The Selected Knowledge for the Design Workshop.

Alongside the booklet, several additional instruments are provided to assist participants during the design session (Figure 7.2): (1) site photos: this set includes a bird's-eye view photo of the testing site and a series of detailed site photos intended to enhance the participant's understanding of the existing site conditions; (2) A3 size template: this template is designed to visualise the outcomes and specify suggested positions and sizes for the site plan, scenarios, and design descriptions, ensuring uniformity across proposals and facilitating subsequent comparative interpretation; (3) plans and sketches of various scales: these are made available to facilitate brainstorming and enhance communications within teams; (4) post-evaluation form (Appendix C): this includes evaluations of various types of design knowledge, suggestions for improvement, practical feedback, and queries regarding the potential combinations of different types of design knowledge; (5) hand drawing toolset: sets of pencils, markers, and rulers in various colours are provided to assist in the visual representation of ideas. These instruments were integral in enhancing the overall workshop experience, facilitating a deeper engagement with the design session, and enabling more effective communications and visualisations of ideas.

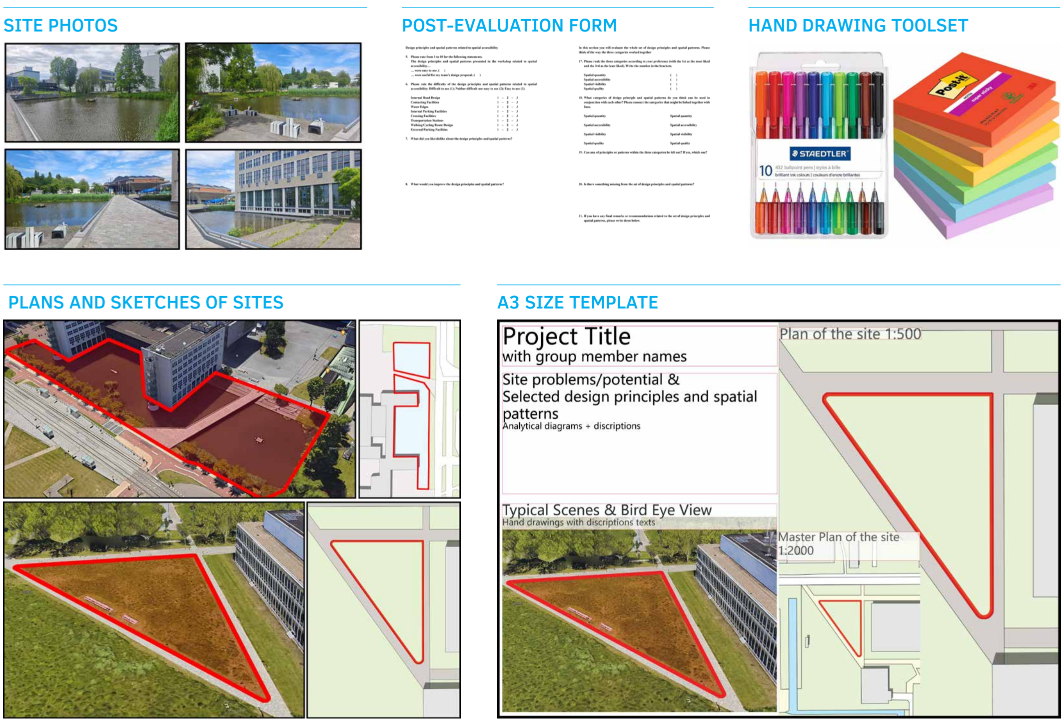


FIG. 7.2 Additional Instruments for the Workshop.

7.2.2 Participant Selection

In this design workshop, 15 participants are grouped into five teams, each consisting of three individuals. Teams are allocated to two test sites for conducting design experiments: two teams at Site A and three teams at Site B. Among the 15 participants in the design workshop, 10 master's students from Delft University of Technology (TU Delft) are pre-selected. PhD candidates from the Department of Architecture and the Built Environment at TU Delft fill the remaining five positions. These PhD candidates are chosen based on their familiarity with the two test sites and their extensive experience in spatial design. As presented in Table 7.1, the participants joining the design workshop include seven students from the Master of Landscape Architecture programme, three from the Master of Urbanism programme, three PhD candidates specialising in urban landscape research, and two PhD candidates from Urban Studies and Architecture Heritage, respectively.

TABLE 7.1 Participants in the Workshop by Selection Procedure, Level of Expertise, and Discipline.

Selection Procedure	Disciplines
Pre-selected – 10 master's students at TU Delft (MA) Selected based on experience: – 5 PhD candidates (PhD)	**Designers** – 7 master's students from the landscape architecture track (LA) – 3 master's students from the urbanism track (UR) Researchers: – 3 PhD candidates from landscape architecture (LA) – 1 PhD candidate from urban studies (US) – 1 PhD candidate from the history of architecture and urban planning (HA)

The determination of the number of test sites and team sizes is guided by three key principles: (1) to ensure diversity and comparability among the results, each site requires the participation of at least two teams; (2) considering the pertinence of the test and participant engagement, the duration of the design workshop is set at approximately 3–4 hours; (3) the workshop should yield relatively comprehensive results that clearly convey the designer's intentions. Consequently, the study opts for two test sites and organises the participants into five teams to conduct the workshops. The composition of the teams is determined based on three criteria (Table 7.2): (1) participants' preferences for the two test sites, (2) prior knowledge and experience with one of the sites, and (3) ensuring a diverse disciplinary mix within each team.

TABLE 7.2 Distribution of the Participants in the Teams by Level of Expertise and Disciplinary Background.

TEAM 1-Site A	TEAM 2-Site B	TEAM 3-Site A	TEAM 4-Site B	TEAM 5-Site A
MA/LA	MA/LA	PhD/US	PhD/LA	PhD/LA
MA/LA	MA/LA	MA/UR	MA/LA	PhD/LA
MA/LA	MA/LA	MA/UR	PhD/HA	MA/UR

7.2.3 Workshop Setup

The structure of the three-hour intensive programme, as depicted in Table 7.3, incorporates a mini-lecture (25 minutes), followed by the design workshop (90–120 minutes), and concludes with a session dedicated to the assessment of outcomes (30 minutes). The workshop is conducted in a designated public classroom within the Department of Architecture and the Built Environment at TU Delft (BG Oost 490), ensuring all activities are centralised and self-contained. Before the design session, the mini-lecture provides a concise introduction to the development of design instruments, specifically design principles and spatial patterns, as well as fundamental background information on the test sites. The lecture serves as essential knowledge to inform the design process and improve the quality of the design outputs. The setup of the workshop required no prior preparation or subsequent work from the participants except for the post-workshop evaluation and the completion of design sketches.

TABLE 7.3 Workshop Process.

0–25Min	30–150Min	150–180Min
Mini-lecture – Brief introduction of the PhD research – The booklet of design principles and spatial patterns – Instructions for the design experiment	**Design workshop** – Understand the sites and identify the potential – Reading the booklet and selecting principles and patterns – Proposing the design schemes – Visualising the design outcomes	**Post-evaluation form** – Comments on the design knowledge – Discussions and reflections on the workshop – Questions

TOC

Site information. Considering the number of participants and the workshop's duration, the study selects two testing sites. The criteria for choosing these sites are based on three main aspects: (1) participants should have prior familiarity with the test sites, as there is no provision for on-site exploration before the workshop; (2) considering the overall duration of the workshop and the expected detail of design outputs, the test sites chosen should be of an intermediate scale; (3) blue space types at the sites should exhibit sufficient diversity to test the adaptability of the design instruments effectively.

Finally, after extensive discussions among the research team and consultations with external experts, two sites within the TU Delft campus were selected for the design workshop (Figure 7.3). Specifically, Testing Site A is situated at the core of the existing TU Delft campus, positioned on the west side of the primary commute for students' daily activities, adjacent to the School of Industrial Design and the School of Mechanical Engineering. The site encompasses an existing blue space featuring a structured body of water with a soft revetment adjacent to the road, seamlessly connecting to both bridges and nearby buildings. The workshop aims to enhance the public visibility and accessibility of this established blue space to harness its health benefits. Testing Site B is situated in the new southern campus of TU Delft, adjacent to the eastern side of the School of Applied Sciences' main building. The site is triangular, enclosed by roads, and currently undeveloped, serving as reserved land for future campus expansions. Presently, it is predominantly covered with herbaceous plants. Unlike Site A, Site B lacks existing bodies of water, requiring participants to introduce new visible and accessible blue spaces into the area.

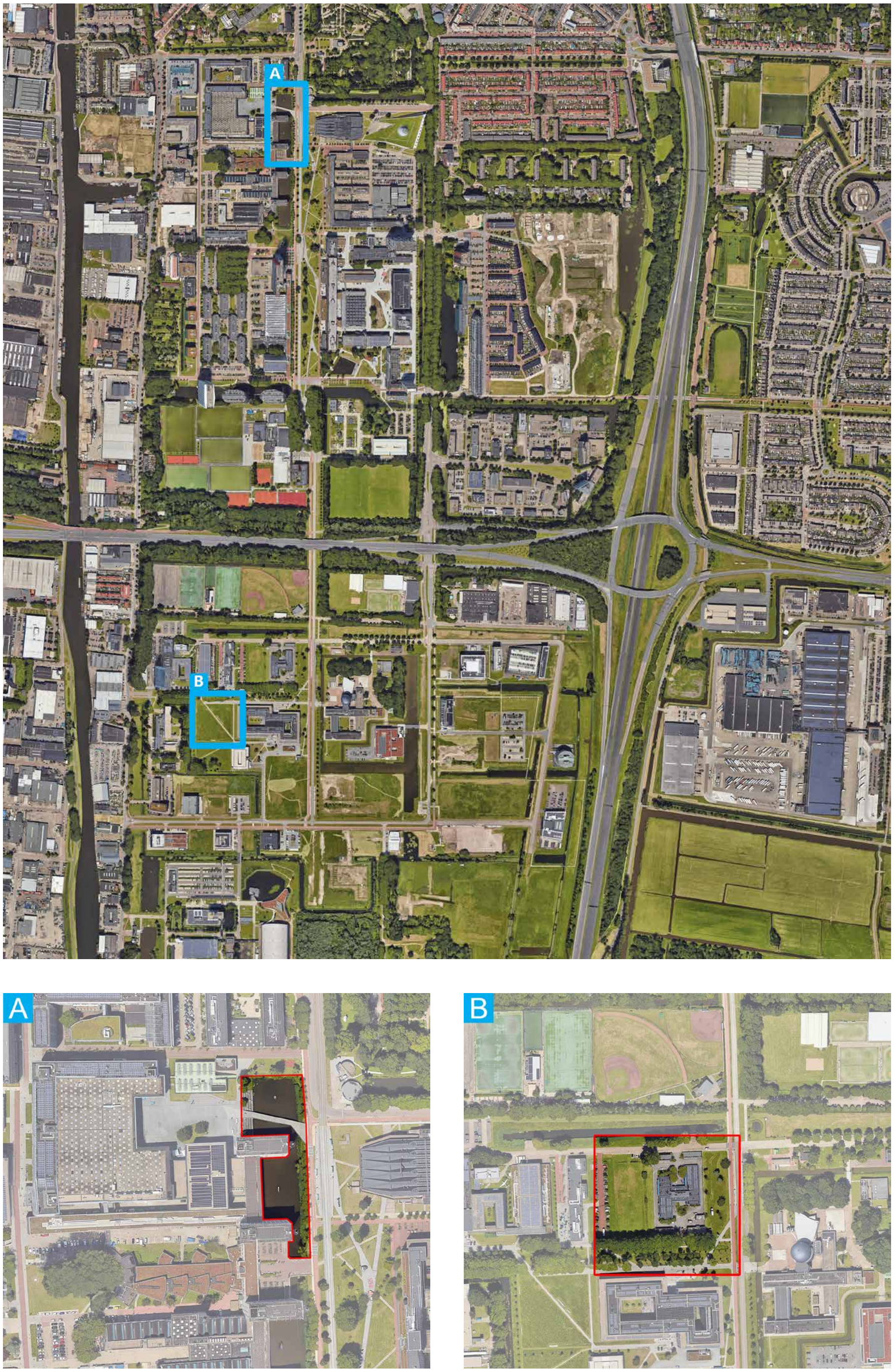


FIG. 7.3 Two Testing Sites on the TU Delft Campus.

Mini-lecture. A mini-lecture was conducted before the workshop design session. This lecture covered three primary elements (Figure 7.4): (1) an overview of the PhD research and the development of the design knowledge, (2) detailed descriptions of the tools and instruments to be utilised in the design workshop, and (3) a guide to the procedures for the upcoming design session, including the schedule and requirements for the design outcomes.

FIG. 7.4 Mini-lecture Before the Design Workshop.

Design sessions. A focused design session occurred approximately 90 to 120 minutes following the mini-lecture (Figure 7.5). During this time, participants actively developed their design proposals with the guidance and assistance provided by the organiser. To further evaluate the usability and effectiveness of the provided design knowledge, the design session was structured such that participants were not mandated to apply the provided design principles. Instead, they were afforded the freedom to either incorporate or disregard the provided design knowledge in their proposals.

To facilitate the efficient management of the design session within a constrained timeframe, the session was strategically segmented into several distinct phases (Table 7.3). Each phase necessitated the completion of specific tasks by the participants, ensuring a structured progression through the design process. First, the initial 15 minutes of the session were dedicated to participants familiarising themselves with the testing site through provided photographs. During this time, they engaged in discussions with team members to identify potentials or challenges related to the public accessibility and visibility of blue space within the testing site. It is important to highlight that Site B initially lacked any bodies of water, compelling participants to create new blue spaces on the site. In the subsequent 20 minutes, participants reviewed the design knowledge provided and selected appropriate design principles and spatial patterns that address the identified site challenges.

FIG. 7.5 The Design Session of the Workshop.

Following this, a 30-minute brainstorming session allowed participants to deliberate and collaborate with their team members to formulate a design proposal for the testing site. During this phase, participants were tasked with actively synthesising the identified site challenges, selected design principles and patterns, and their own design intuition to generate a comprehensive proposal. The final 40 minutes of the session were allocated for participants to work collaboratively, visualising their design proposal to ensure a uniform and coherent presentation layout. Notably, while the aforementioned schedule outlines specific timings and tasks for each phase, these serve merely as recommended guidelines. Participants were allowed the flexibility to dynamically adjust their workflow according to their progress and preferences throughout the session.

7.2.4 Data Collection and Analysis

To evaluate the design workshop and the use of the instruments, a mixed method approach is used to collect data, emphasising how the participants understand the design principles and spatial patterns, as well as their application potential. Specifically, three methods are adopted to record and evaluate the process and outcomes of the design session:

- External observation: This consists of a non-participant observational approach undertaken by the organiser, who does not engage directly in the design process. During this phase, the observer records detailed notes, photographs, and videos of the participants' interactions and behaviours within the design session.
- Post-workshop evaluation: At the end of the workshop, participants complete a structured, paper-based questionnaire designed to assess the effectiveness of the instruments employed in their design and the quality of the developed design knowledge.
- Design outcomes: The design projects are presented using standardised formats, which include master plans produced at uniform scales, comprehensive written descriptions, and hand drawings of future scenarios. This methodological approach facilitates subsequent detailed analysis and comparisons across projects.

Two distinct methods are employed to investigate the application of design knowledge and potential improvements, contingent upon the variety of data collected: (1) summary statistics: mean and standard deviation of values recorded in 10-point Likert scale questions within the post-evaluation form, showing overall scores and agreement for the design knowledge; (2) content analysis: identifying the participants' opinions on application potential and future improvements of design knowledge based on the open-ended questions, observations, and design outcomes.

7.3 Results

7.3.1 The Practical Knowledge Used in the Design Process

Data collection proceeded smoothly, with each participant completing the post-evaluation form, although some omitted certain questions due to their lack of utilisation of specific design knowledge during the session. The application of design knowledge across four themes is analysed based on responses to questions listed in Table 7.4, focusing on (1) ease of use, (2) usefulness, (3) influence on the design process, and (4) suggested improvements. Additionally, the overall utility of the design knowledge and the interrelationships among various themes are assessed in terms of (1) the relative attractiveness of the design knowledge across different themes, (2) the potential for integrating different types of design knowledge, (3) the completeness of the provided design knowledge, and (4) suggested enhancements.

TABLE 7.4 Questions in the Post-evaluation Form.

QUESTION	10-point scale	3-category / Ranking	Open question
Questions related to each theme of design knowledge			
How easily can design knowledge be applied to design?	✓		
How useful is the design knowledge in the design?		✓	
What are the participants' preferences for design knowledge?			✓
How can the design knowledge be improved?			✓
Questions related to the whole set of design knowledge			
How do the four types of design knowledge rank in terms of attractiveness and importance, and why?		✓	
Which of these four types of design knowledge can be combined and applied?			✓
Should any of the four types of design knowledge be left out? If so, which one(s) and why?			✓
Is there something missing from all the design knowledge?			✓
How can the design knowledge be improved overall?			✓

Spatial quantity. The design knowledge aimed at enhancing the spatial quantity of blue space was the initial tool introduced during the workshop. It encompasses two main components: (1) three distinct design principles for increasing the quantity of blue space along with corresponding spatial patterns, and (2) various types of blue space that exist in urban environments, accompanied by examples. Specifically, the design principles and spatial patterns guide practitioners on how to increase blue space quantity, while the categorisation of blue space types offers a comprehensive selection of options available for improvements. The results indicate that the design knowledge about spatial quantity is generally easy for participants to utilise and straightforward to incorporate into their design proposals (Table 7.5). Participants also found the two specific components accessible and straightforward to apply, with no one reporting difficulties in implementation (Figure 7.6).

TABLE 7.5 Summary of the Scores and Level of Agreement on the Ease of Use and Usefulness of the Four Types of Design Knowledge.

		Quantity	Accessibility	Visibility	Quality
Ease of use	Mean	8.067	8.133	8.000	7.929
	SD	0.961	1.125	1.080	0.997
Usefulness	Mean	8.083	8.400	8.000	8.455
	SD	0.996	0.986	1.477	0.522

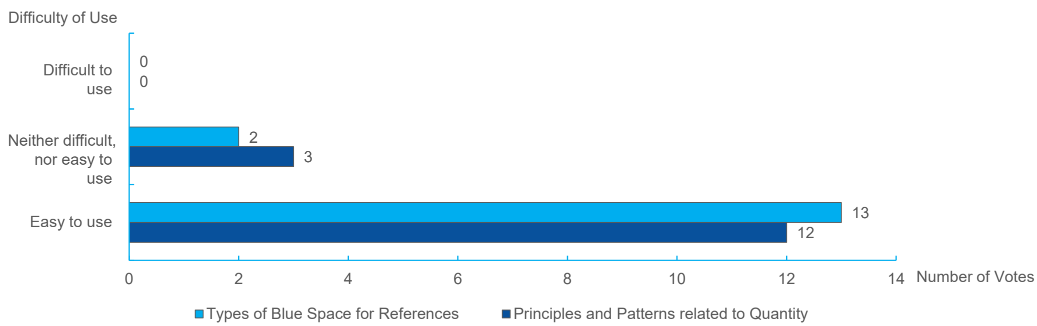


FIG. 7.6 The Difficulty of Applying the Design Knowledge Related to Quantity, as Perceived by the Participants.

Table 7.6 presents feedback from participants on the design knowledge related to increasing the number of blue spaces alongside their suggestions for enhancements. A commonly appreciated aspect is the clear representation of the design knowledge, which was classified and organised clearly. Additionally, participants note the ease of application, attributing this to the clear linkage between design principles or spatial patterns and blue space typologies, as well as the inclusion of practical examples.

TABLE 7.6 Comments of Participants on Design Knowledge Related to Quantity.

Advantages	Recommendations
– Clear representation and repetitive style; Different forms of explanations; Clear focus. – The design typology is very interesting; We can pick up similar patterns and related strategies to redesign site one. – Good to have corresponding examples of different spatial typologies. – Spatial patterns were easy to understand and not specific so that they could be easily applied to other contexts.	– Lack of information about the relations between inland functions or other sides of bodies of water. – More principles can be considered, especially for a specific site; Make them more campus-specific, local scale instead of a bigger scale. – Perhaps more variations on each principle. – The paved area sometimes may not connect to a water-friendly design.

On the other hand, the unique characteristics of the testing sites led some participants to suggest that the design principles and blue space typologies should incorporate more detailed and site-specific features. This perspective led to debate, as others found that the generic nature of the design knowledge facilitates more creative thinking during its application. Additionally, some participants noted that the current design knowledge appears overly complex and relies too heavily on paved surfaces in visualisations, which could potentially lead to misunderstandings.

As stated in the suggestions for improvement, enhancing the utility of design knowledge could be achieved by providing a more detailed description of its components and the way they function, accompanied by relevant examples. This feature would better tailor the use of design knowledge to site-specific characteristics. Moreover, when visualising design principles, spatial patterns, and blue space types, it is crucial to diversify the background elements used in these visualisations. This approach helps prevent the repetition of elements, which could lead to misunderstandings among potential users.

Spatial accessibility. Design knowledge for enhancing the accessibility of blue space is considerably more complex than that related to increasing blue space quantity and served as the primary tool for participants in the workshop. Due to the limited total duration of the workshop and the need to focus during the design session, only design knowledge applicable at the local level was included. This knowledge is structured around various blue space elements such as internal road design, contacting facilities, water edges, internal/external parking facilities, crossing facilities, transportation stations, and walking/cycling route design. Each element may encompass multiple design principles and corresponding spatial patterns designed to improve accessibility to blue spaces. Overall, participants found the design knowledge aimed at enhancing the accessibility of blue spaces easy to use, and they actively incorporated it into their design proposals (Figure 7.7). However, there were variations in participant responses across different elements. Specifically, design principles and spatial patterns related to internal road design, access facilities, crossing facilities, and water edges received high ratings from participants for usability. In contrast, the principles and patterns concerning internal and external parking facilities, as well as walking and cycling route design, received neutral ratings from many participants, indicating these aspects are neither particularly difficult nor easy to apply. Many participants found the principles and patterns related to transportation stations challenging to apply in their designs.

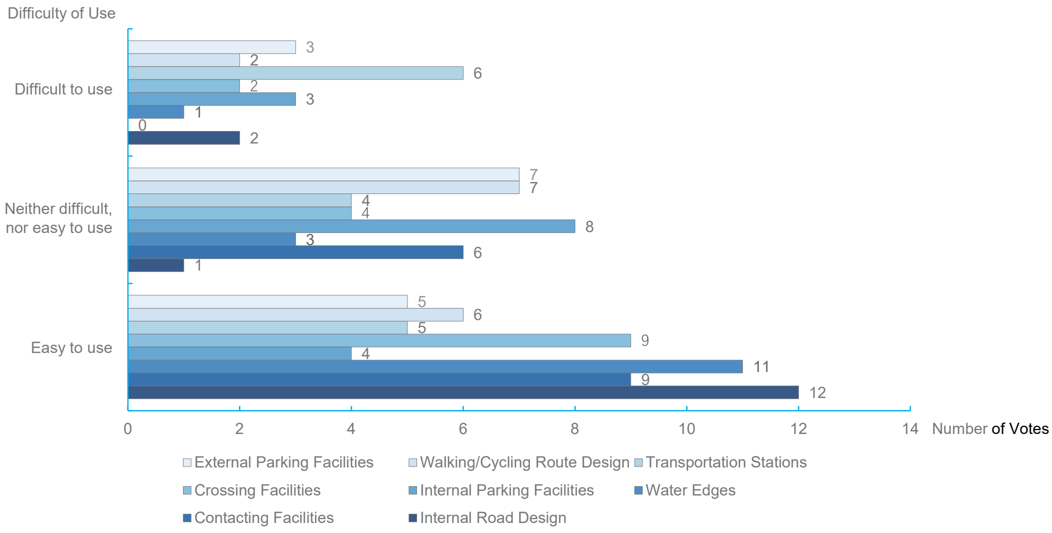


FIG. 7.7 The Difficulty of Applying the Design Knowledge Related to Accessibility, as Perceived by the Participants.

According to participant feedback (Table 7.7), the design knowledge focused on enhancing blue space accessibility addresses three key aspects: (1) the design principles and spatial patterns are clearly and effectively presented through a combination of diagrams and explanatory text; (2) the spatial elements that potentially influence blue space accessibility are thoroughly considered, with corresponding design strategies articulated clearly; (3) specific design knowledge, particularly pertaining to road and waterside design, is highly rated by participants for its practical application potential.

TABLE 7.7 Comments of Participants on Design Knowledge Related to Accessibility.

Advantages	Recommendations
– Clear representation and repetitive style, clear to understand; different forms of explanations. – I like the way that the booklet presents the principles with illustrations; it is very clear and easy to understand. – It is really detailed. – Not too site-specific, but still very useful. It is easy to know how to use them. You give precise illustrations of the patterns, and it is a readable way for practitioners. – I would like to have more reflections on proposals and also some inspirations besides your inputs, like the platform inspiring us to think about an alternative form like floating islands.	– Crossing\walking facilities and route design were difficult to use because of the site conditions. – Maybe there could be more interventions on combinations of activities (parties + walking, crossing + walking) and activities related more to the location (study + walking). – Also, patterns to access the water?; Maybe some quay? – They all were really urban (e.g. straight edges, big streets, small bodies of water). – I want these patterns to give me some scores for each part (visibility, accessibility) so that I can know how to use them.

Conversely, participants identified several limitations in this segment of the design knowledge. For instance, many diagrams depicting spatial patterns predominantly feature river courses within urban environments as typical scenarios, which may restrict the ability to generalise these patterns to other settings. Further, certain specific principles and patterns are noted as challenging to implement at the testing sites. Participants also emphasise the importance of considering how different factors apply to design knowledge to delineate clear application contexts. This approach should include taking into account the needs of specific population groups, particularly vulnerable ones, as well as the unique characteristics and potential of various site environments.

Participants also offer several suggestions for improvement, encompassing three main aspects. First, there is a call for explicit recommendations on how different principles and patterns might be combined. Participants note that in practice, the integration of multiple principles and patterns often yields synergistic effects. Second, specific enhancements to individual principles and patterns are proposed. For instance, participants suggest providing more diversified access to water beyond mere contact and recommend expanding the visual representation of blue spaces to encompass a broader range of information about the surrounding environment. Lastly, there is a recommendation to evaluate the effectiveness of the application of different principles and patterns to help clarify practical priorities and optimise design outcomes.

Spatial visibility. Similar to the knowledge for enhancing blue space accessibility, the design knowledge for increasing blue space visibility is structured based on various spatial elements of blue space, including internal/external vegetation, water edges, internal roads, viewing facilities, and building design. Consistent with the aforementioned accessibility, only the design principles relevant to the local level, along with their corresponding spatial patterns, are integrated into the workshop as design instruments. The evaluation results for the design knowledge related to blue space visibility indicate that it has strong application potential and is generally easy to use (Figure 7.8). However, as with the design knowledge for accessibility, participants' assessments of different design principles and spatial patterns vary. Specifically, design knowledge concerning internal road design, viewing facilities, water edges, and internal vegetation design is widely recognised as being easy to apply. In contrast, principles and patterns associated with building design and external vegetation design receive lower marks. Notably, nearly one-quarter of the participants find the knowledge related to building design challenging to use.

Similar to the advantages observed regarding knowledge related to accessibility, participants find the knowledge for improving visibility to be generally clear, comprehensive, and practical to apply (Table 7.8). Furthermore, several individual design principles and spatial patterns significantly impact participants due to their significant application potential, particularly those related to water edges, viewing facilities, and internal vegetation design.

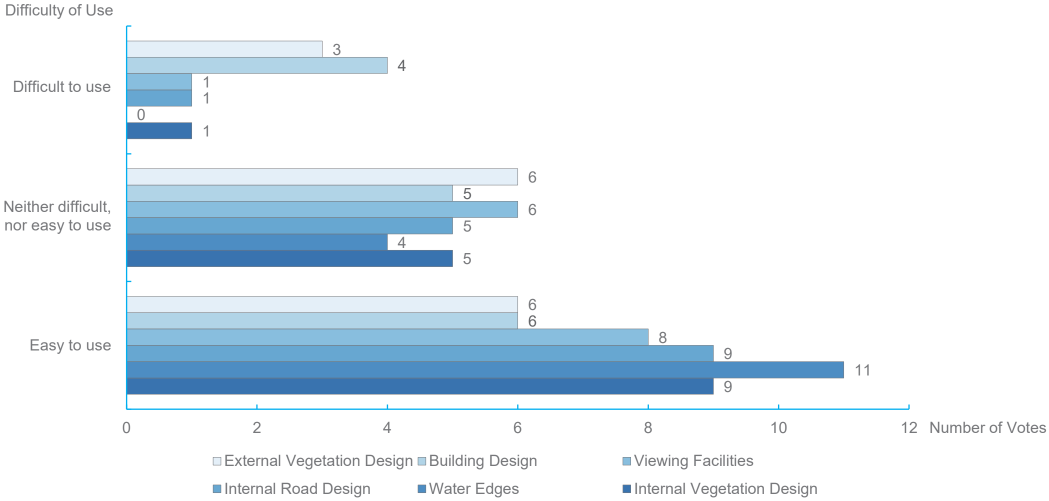


FIG. 7.8 The Difficulty of Applying the Design Knowledge Related to Accessibility, as Perceived by the Participants.

TABLE 7.8 Comments of Participants on Design Knowledge Related to Visibility.

Advantages	Recommendations
– It's nice that patterns are not too complicated. That gives space for creation. – I appreciate the soft edges design; I like the water edges and facilities. – Good! It was a nice guide to help with the design processes. – I like the water edges and facilities. – I like the way you present and the ideas behind it. – It's comprehensive when it comes to the principles itself.	– A lot of the patterns are similar to accessibility; Do not use the same as accessibility. – Maybe we should consider a bit from the perspective of different groups, like the visibility for whom? Divide different degrees of visibility for different groups of people. – For external vegetation, I do not use it a lot. – More patterns should be used to target the relationship between building and visibility, like main entrances or building directions. – For giving a view corridor, the removal of trees is going to be debatable. So, I would suggest thinking about the ecosystems. – Should refer more to the surrounding environment.

On the other hand, participants identify certain potential limitations, notably that some design knowledge overlaps with that related to accessibility, which poses challenges to their understanding. Further, participants concur on the importance of clearly delineating the scenarios and populations for which different design principles and patterns are applicable. This clarity could significantly aid practitioners in selecting the most appropriate principles and patterns for their projects. Moreover, participants raise concerns about the usability of certain principles and patterns. For instance, some question the practical application of design knowledge concerning external vegetation and the feasibility of adjusting tree positions to create view corridors.

Participants provide suggestions for improvement in three aspects: (1) enhancing the diversity and novelty of the principles and patterns, such as optimising building entrances and orientations, along with improving the transparency of building facades; (2) considering and elaborating on the adaptation potential of principles and patterns to different environments – for instance, examining the ecological impacts of relocating trees to create view corridors; (3) similar to considerations for accessibility, some principles and patterns should account for a broader environment, extending beyond bodies of water and spatial elements.

Spatial quality. The study also seeks participants' opinions on design knowledge related to improving the quality of blue space, as captured in the post-evaluation form, although this knowledge was not required during the design session. To ensure that participants were acquainted with this aspect of design knowledge, the generation process and contents of this quality-related knowledge were introduced in the mini-lecture that was conducted before the design session. Additionally, participants were allotted ample time to review the corresponding principles and patterns during the evaluation phase, facilitating a thorough understanding and thoughtful feedback. Overall, participants report that the design knowledge related to improving spatial quality is easy to understand and holds strong application potential (Figure 7.9). Specifically, the majority find the design knowledge pertaining to running/cycling route planning and internal vegetation design straightforward and easy to use. However, the principles and patterns related to building and traffic elements, as well as public facilities, receive more neutral evaluations regarding their application potential.

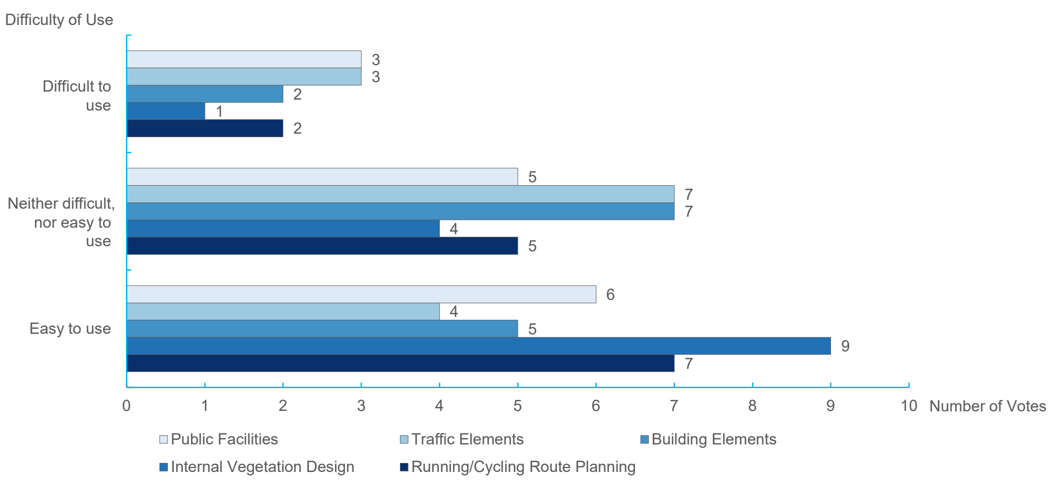


FIG. 7.9 The Difficulty of Applying the Design Knowledge Related to Quality, as Perceived by the Participants.

Since the design session did not require participants to apply the design knowledge related to spatial quality, their feedback was based on their design intuition while filling out the post-evaluation form (Table 7.9). Consequently, compared to the feedback on the other three types of design knowledge, the insights provided for quality-related knowledge are less detailed and more limited. Generally, participants recognise the practical value of the knowledge for improving spatial quality and commend the consideration of diverse population groups and activity types in the formulation process, which they believe significantly enhanced the application potential of the knowledge.

TABLE 7.9 Comments of Participants on Design Knowledge Related to Quality.

Advantages	Recommendations
– I like the principles already considered a lot about human activity. – The design principles take account of the perceptions. – I know how to integrate different elements and understand the sequence in which they should be arranged. – It is not specific enough to apply to the site/ other site. – Different scales, easy to follow. – It was direct and easy to use.	– Traffic and route planning were difficult to use because of the site's existing conditions. – Maybe make it clearer what type of water edge goes with which activity. – There could be more variation for public facilities of building elements or vegetation to incorporate it in different configurations. – Considering soft riverbank or ingredient. – We need more information about the bigger scale to apply them.

The limitations and suggestions regarding this part of design knowledge predominantly pertain to the comprehensiveness of its content. Some participants observed that the current design knowledge encompasses only a limited array of spatial elements, leaving many potential applications unexplored. Additionally, several participants noted that some of the design knowledge presented, such as the planning of cycling and walking routes, might be more appropriately classified as district-scale design knowledge rather than local scale.

The combination of practical knowledge from different design themes. In the ranking of the four types of design knowledge according to the preference of the participants, as reported in the post-evaluation form (Figure 7.10), the design knowledge related to improving spatial accessibility scores the highest, followed by the knowledge related to visibility and quality, while the knowledge related to quantity is the less preferred design instrument. Specifically, over 60% of participants favoured design knowledge pertaining to accessibility, ranking it as the most preferred among the four design knowledge categories, with only one individual expressing dislike. In contrast, more than half of the participants expressed the least interest in knowledge aimed at improving quantity, with only one person ranking it as their top choice. Regarding design knowledge that enhances visibility and quality, participants demonstrated similar preferences for both, typically ranking them in the middle two positions of the four categories. This tendency can be attributed to the richness of content and application potential at the testing sites. The design knowledge for improving accessibility, which includes the most extensive array of design principles and spatial patterns and is most frequently employed in design testing, was preferred more highly. Conversely, the design knowledge concerning the quantity, which has the least content and the fewest applications related to the testing sites, was less favoured.

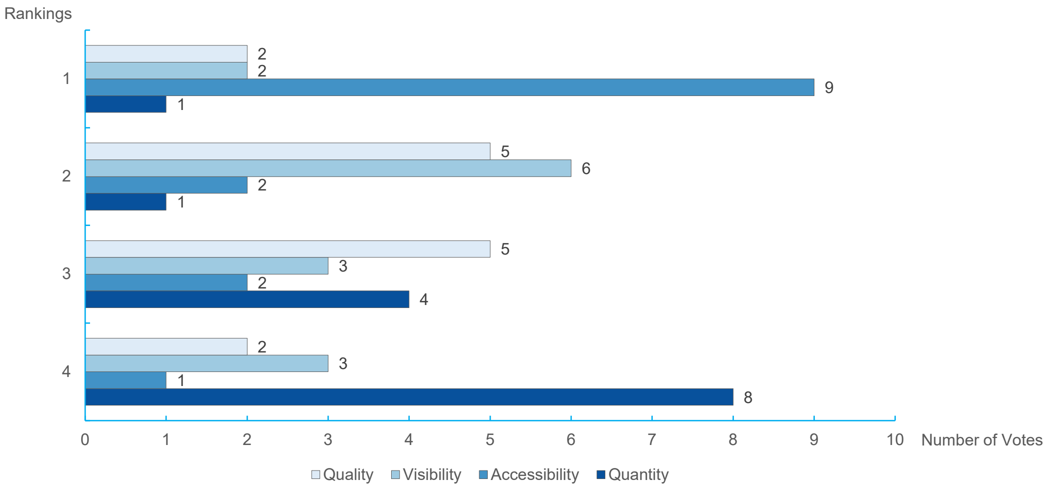


FIG. 7.10 The Order of the Four Types of Design Knowledge as Proposed by Participants.

On the other hand, the evaluation form requires participants to identify which types of design knowledge could be effectively combined (Table 7.10). Generally, the design knowledge focused on improving accessibility is found to be the easiest to integrate with other types of design knowledge. This subject is followed by design knowledge related to improving visibility. Conversely, the design knowledge associated with quality and quantity is considered the most challenging to combine with other types of design knowledge. The reasons for this phenomenon may be attributed to several factors: (1) participants perceived the task of increasing quantity as more challenging than other aspects, which may weaken its integration with other types of design knowledge; (2) the study only explores and presents a limited amount of design knowledge related to quality, potentially leading to an underestimation of its adaptability; (3) accessibility and visibility were concepts familiar to the participants, and their understanding of these aspects was further reinforced through their primary design objective when designing the testing sites.

TABLE 7.10 The Connections Among Four Types of Design Knowledge.

	Quantity	Accessibility	Visibility	Quality
Quantity		11	5	4
Accessibility	5		12	5
Visibility	4	9		7
Quality	5	9	9	

When asked whether any of the four types of design knowledge could be omitted, approximately two-thirds of respondents (9 out of 15) indicated that all knowledge is valuable and should be retained. The remaining respondents who believe that some design knowledge could be discarded focused on three main aspects: (1) two participants suggested that the design knowledge related to quantity should be omitted because its implementation is both challenging and fundamental; (2) two others proposed discarding the design knowledge related to visibility and quality, citing its lack of application during the design sessions; (3) two respondents felt that certain specific design principles and spatial patterns, particularly those that are redundant across different categories of design knowledge, should be left out.

When asked about any missing content in the current four types of design knowledge, respondents highlighted three key areas: (1) the need to specify the target audience for the design (e.g. older people, teenagers), especially in presentations of local-scale design knowledge; (2) the importance of exploring the interplay between the current health-oriented design knowledge and other potential areas of design knowledge, such as those aimed at ecological and functional objectives; (3) addressing the noticeable absence of certain specific principles and patterns, particularly those related to sightlines, shadows, vegetation, and in-water facilities.

Overall, participants were positive in their evaluation of the four types of design knowledge, recognising links among them and acknowledging the potential for further improvement. Notably, the design knowledge related to accessibility was deemed the most popular and adaptable. Conversely, the design knowledge focused on increasing quantity was the least popular among the four categories. Regarding the design knowledge pertaining to quality, the current study only showcases results from site-based evidence translation, which displays promising application potential. This knowledge was well-received, largely because it takes into account the diverse needs of different types of people and activities.

7.3.2 Design Outcomes

Unlike traditional design courses that necessitate a comprehensive assessment of design proposal quality, the primary objective of this workshop was to evaluate the practical applications of the proposed design knowledge. Consequently, the workshop did not assign scores to each team's design proposals. Instead, it concentrated on discerning the potential and limitations of knowledge application by analysing the proposals presented. Among the five design proposals submitted, three selected Site A as their testing ground, while two opted for Site B. Sketches were also preserved as supplementary materials to thoroughly illustrate the participants' thinking process during design sessions, providing insights into the participants' application of design knowledge.

Of the three teams that selected Site A (Figure 7.11), the design titled 'Sight 1' has minimal impact on the original situation. In their site analysis, the team addresses visibility and accessibility challenges from two distinct angles. First, considering that the road and dense vegetation obscure the east side of the body of water, the renovation strategy focuses on reconfiguring the vegetation along the waterside in conjunction with the existing sculptures to enhance visibility. Secondly, for the bodies of water located near buildings and open spaces on the west, north, and south sides, the proposal advocates introducing on-water facilities to improve accessibility.

'SIGHT 1' OF SITE A BY TEAM 1

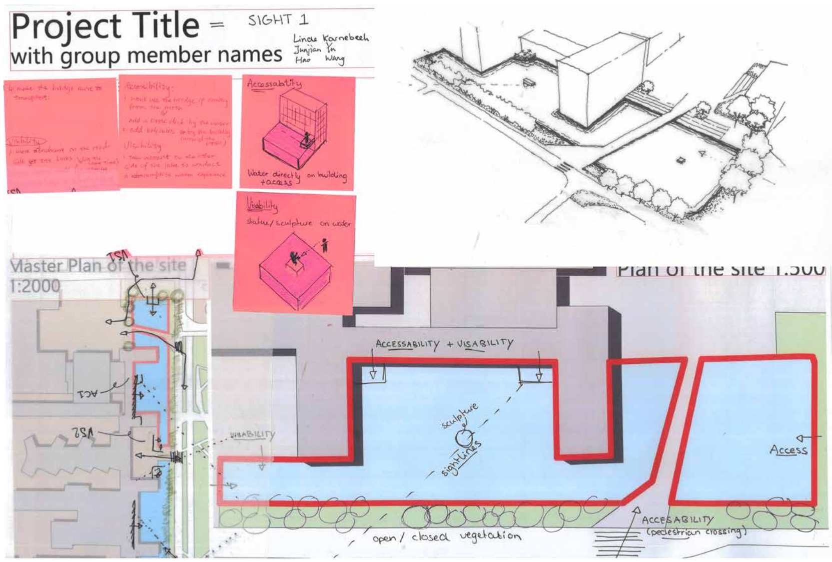
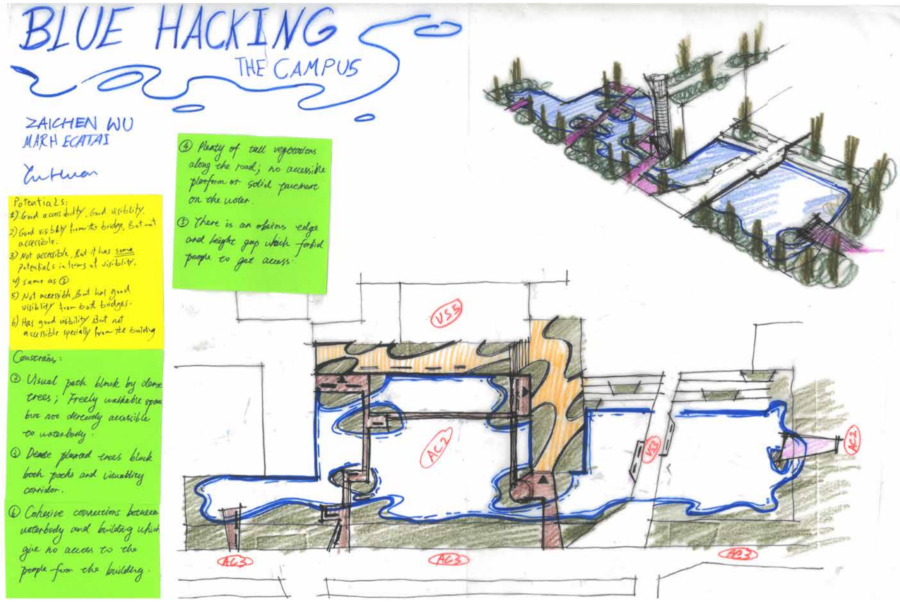


FIG. 7.11 The Design Outputs of Site A by Three Teams.

'BLUE HACKING' OF SITE A BY TEAM 5



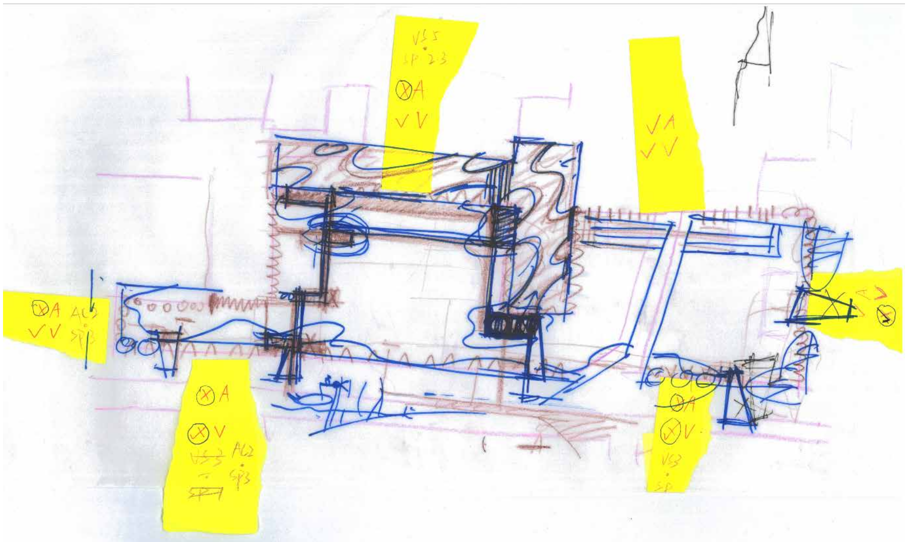


FIG. 7.11 The Design Outputs of Site A by Three Teams.

'SHAKE IT UP' OF SITE A BY TEAM 3

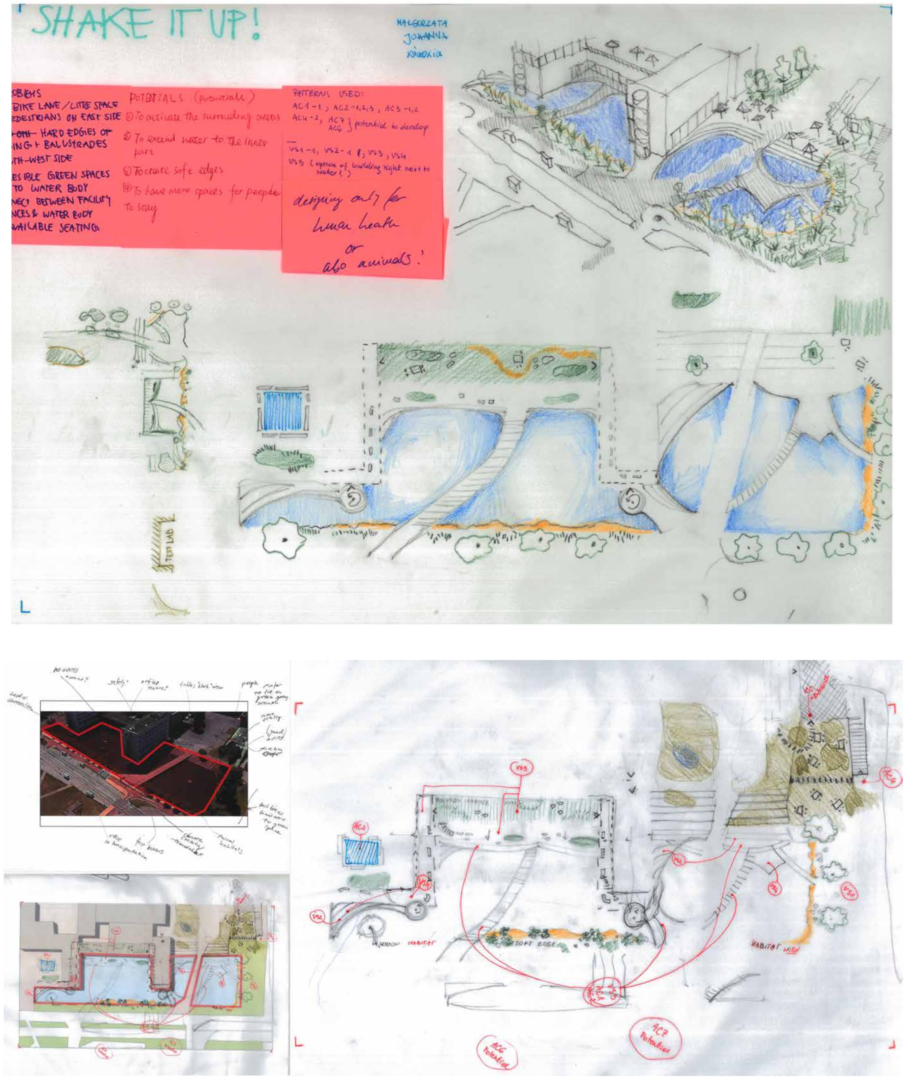


FIG. 7.11 The Design Outputs of Site A by Three Teams.

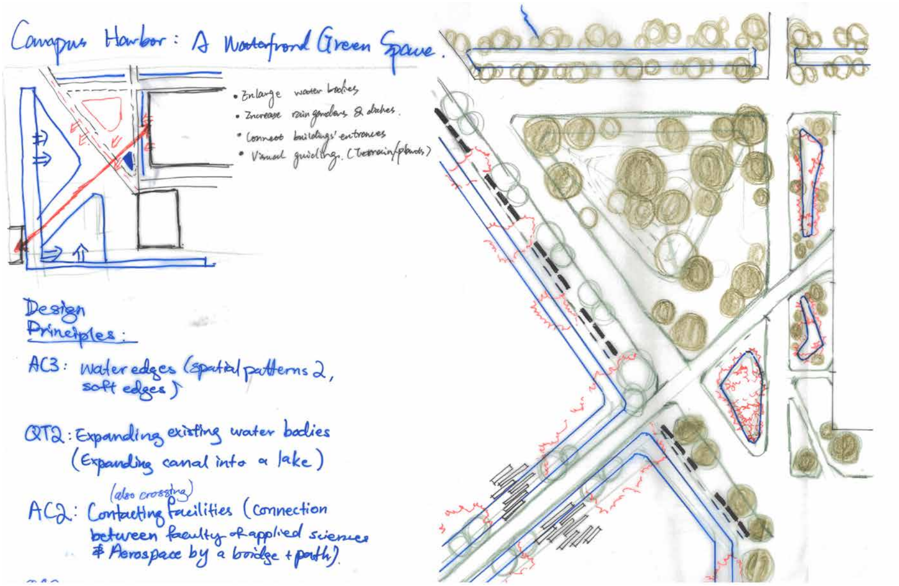
In contrast to the conservative strategies of ‘Sight 1’, the project titled ‘Blue Hacking’ adopts more audacious strategies, actively integrating elements of the surrounding environments to enhance the visibility and accessibility of blue spaces. The team initiates the process by conducting a thorough assessment of the accessibility and visibility on each side of the existing body of water, identifying specific challenges that need addressing. Following this analysis, they select appropriate design principles and spatial patterns that could be effectively applied to develop a robust design proposal. The proposal enhances public accessibility and visibility of the blue space mainly through three interventions: (1) it modifies the original body of water and surrounding vegetation to increase visibility while adding floating islands to enrich the landscape; (2) it introduces platforms and walkways to facilitate direct interaction with the water, thus improving accessibility; (3) it integrates the design with surrounding architecture by establishing platforms and roof gardens that visually and functionally connect with the water.

Similarly, the ‘Shake It Up’ project extensively incorporates on-water platforms as a strategic measure to enhance water accessibility and visibility. Initially, the team conducts a thorough analysis of the water’s edge within the site, pinpointing challenges related to public accessibility and visibility. Subsequently, they select relevant design principles and spatial patterns. Like ‘Sight A’, this project underscores the interrelationship of roads, sculptures, and buildings; however, it distinguishes itself by utilising on-water platforms to establish these connections. In contrast to the ‘Blue Hacking’ project, the on-water platforms in ‘Shake It Up’ are designed with curvilinear forms that link various elements of the site, including squares, buildings, and riverbanks. Furthermore, the project integrates the body of water into the square, creating a fountain that enhances the aesthetic qualities of the blue space.

As Site B lacks blue space, participants are required to add blue spaces within the site. The design projects from the two teams that selected Site B present divergent concepts (Figure 7.12). First, the ‘Campus Harbour’ design opts not to create a large body of water within the site but rather to surround the site with extensive aquatic areas, situating only a modest body of water in the southeast corner. This configuration allows the site to act as a transitional zone, linking the surrounding buildings to the expansive body of water. Additionally, the design elevates the terrain in the northern part of the site, where seating is strategically placed in the raised areas, significantly enhancing the visibility of the blue space for the surrounding areas.

TOC

'CAMPUS HARBOUR' OF SITE B BY TEAM 2



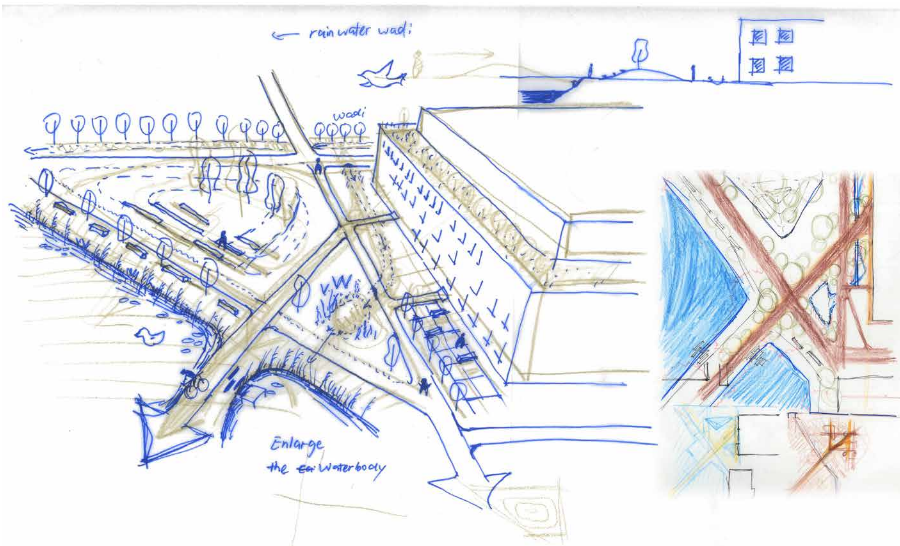
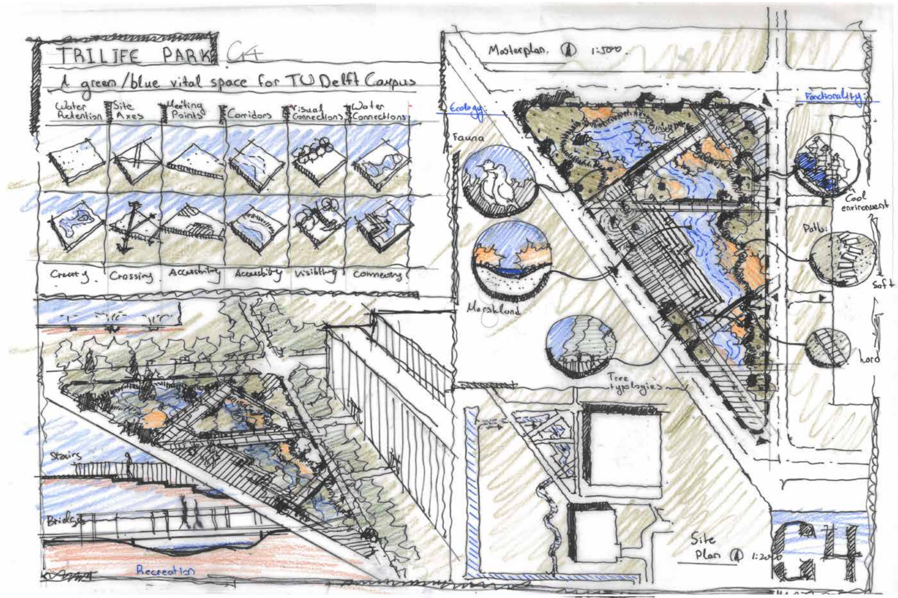


FIG. 7.12 The Design Outputs of Site B by Two Teams.

‘TRILIFE PARK’ OF SITE B BY TEAM 4



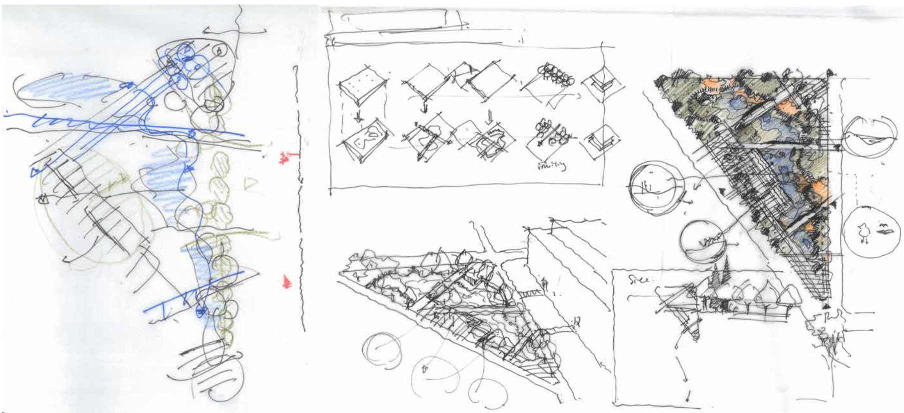


FIG. 7.12 The Design Outputs of Site B by Two Teams.

Another design for Site B, named 'Trilife Park', is visually striking, with drawings that effectively depict the scheme from multiple perspectives. This design introduces a substantial body of water within the site, utilising both surrounding water sources and rainwater collection techniques. It facilitates diverse forms of public interaction with the water, incorporating facilities like platforms, fountains, and steps, which allow for direct contact and engagement with the bodies of water. Notably, the project pays attention to the consistency among various elements, particularly in the selection and spatial organisation of vegetation. This consideration significantly enriches the environmental diversity and aesthetic appeal of the site. Both designs emphasise the connectivity between different roads and surrounding buildings, with carefully planned road networks that facilitate blue space access across various areas.

Overall, the projects developed during the workshop effectively utilise the provided design knowledge to varying degrees, achieving both depth and innovation in spatial strategies and schemes for the selected sites within a limited timeframe. Notably, many teams choose not to adhere rigidly to provided design principles and spatial patterns. Instead, they apply them adaptively, merging them with the specific characteristics of the site and the design intentions of the participants. This approach allows for the creation of tailored and effective solutions that respond dynamically to the unique demands and opportunities of each site.

7.4 Discussion

As presented above, the design workshop has been employed to demonstrate and test the application of the design knowledge in a real-world context. Subsequently, post-evaluation forms are utilised to gather participants' preferences and opinions on various types of design knowledge, as well as their suggestions for further enhancements. Insights regarding the application of design knowledge, recommendations for improvement, and methodological challenges have been identified and discussed below based on observations from the design sessions, design outcomes, and results from the evaluation forms.

7.4.1 The Usage of Practical Design Knowledge

Although participants recognised all four types of design knowledge as necessary and practical for application, their feedback highlights variations in application potential. Specifically, design knowledge related to accessibility and visibility is considered more desirable and easier to implement compared to design knowledge aimed at improving quantity and quality. The potential reasons for these differences, as elaborated in the evaluation form, can be attributed to three aspects. First, the design knowledge related to accessibility and visibility is more comprehensive and richer compared to that concerning quantity. The relative simplicity of the quantity-related design knowledge may lead participants to believe they already possess sufficient understanding in this area, which could limit their assessment of its application potential. Second, due to the mature blue space at Site A, the design knowledge concerning quantity was not integrated into the design process, resulting in participants' unfamiliarity with this segment of design knowledge. Third, while the design knowledge related to improving quality is commended for considering the characteristics of different populations and activities, the current scarcity of evidence-based translations has led to a constrained evaluation of its usage potential. These factors indicate that practitioners should carefully select appropriate design knowledge and actively reflect on its limitations during the application. This reflection guides improvements in how design knowledge is articulated and implemented in future practices.

During the on-site observations of the design session, it was noted that most participants selected design knowledge while analysing site-specific problems or after identifying these problems. Typically, participants quickly reviewed all available design knowledge and then consulted with team members to decide which knowledge to apply to their designs. Given that the workshop was limited to testing only a select amount of local-level design knowledge, the selection process was somewhat streamlined. Incorporating multi-scale design knowledge into practice necessitates clear organisational structures to aid designers in quickly identifying and accessing applicable design principles and spatial patterns. This process can be facilitated through several approaches. First, designers can sift through available design knowledge based on the scale of their projects, allowing them to narrow down relevant principles and patterns more efficiently. Second, they can use different spatial elements to expedite the selection of appropriate design knowledge. Often, the problems identified at a site are closely tied to specific spatial elements, making them valuable criteria for selecting relevant design knowledge. Finally, design intentions can guide the selection of suitable design knowledge. For instance, some participants noted that due to the extensive visibility of Site B to its surroundings, the focus of spatial interventions should primarily be on enhancing accessibility rather than visibility.

After analysing the process and the dimensions involved in selecting suitable design knowledge during design practice, it is essential to identify which content within the design knowledge can facilitate this process effectively. Firstly, a catalogue reflecting an overview of available design knowledge and types of spatial elements should be clearly presented, allowing practitioners to locate corresponding knowledge quickly. Secondly, specific design principles and spatial patterns should be introduced briefly, with direct visualisations and case study combinations to aid practitioners in rapidly understanding and determining their applicability. Thirdly, while comprehensive information is essential, the presentation of design knowledge should avoid excessive specificity and complexity, which may restrict its adaptability and replicability. Fourthly, it is crucial to identify potential limitations of the design principles and spatial patterns during the application process and to delineate their application scenarios, thereby supporting practitioners' selection. Lastly, guidelines for their integrated application should be provided to facilitate the collaborative use of various design principles, spatial patterns, and cross-types of design knowledge.

7.4.2 Improvements in Practical Design Knowledge

Based on reflections from the design sessions and the usability of design knowledge, along with participant feedback collected through the evaluation forms, several practical suggestions for enhancing the current design knowledge are summarised and proposed.

Firstly, although the booklet proposed in this research include catalogues designed to help practitioners quickly locate various types of design knowledge, the lack of an overview of blue space elements presents challenges in efficiently finding them. As noted in participant comments, it can be difficult for practitioners to understand the relationships among different spatial elements and surrounding environments. Therefore, it is essential to delineate the different spatial elements of blue spaces at the beginning of the booklet and to provide visualisations that assist practitioners in clarifying the scope of the principles and patterns.

Secondly, there is a need to enhance the logic and practicality of the numbering system for design principles and spatial patterns. Some participants noted that while the current numbering system does provide a means to distinguish between different pieces of design knowledge, incorporating references to associated spatial elements directly within the numbering could more accurately locate relevant design principles and patterns. Moreover, there are duplications among some of the current design principles and spatial patterns, particularly within the design knowledge related to accessibility and visibility. Therefore, it is necessary to consider eliminating redundant content and replacing it with a more efficient numbering or naming system to enhance clarity for users.

Third, it is crucial to refine the presentation of spatial patterns to prevent potential misunderstandings. The direct and spatial nature of design knowledge, especially spatial patterns, often leads practitioners to consider their applicability at specific sites prematurely. Feedback has highlighted that current design knowledge lacks emphasis on the unique characteristics of different contexts, such as campus environments, and often uses linear urban blue spaces as default backgrounds in visualisations. However, the primary aim of design knowledge is to serve as a reference for designers, aiding them in adapting it to specific sites. Given that the background of visualisations is secondary to the conveyed knowledge, it is essential to diversify the forms of visualisations and enhance the articulation of core content. This process will improve the comprehensibility and applicability of the design knowledge.

Fourth, it is essential to detail the application scenarios for various design principles and patterns alongside their potential for integration. There is a recognised need for specific application-level guidance and the possibility of synergies between different types of design knowledge. Enhancements can be made by providing comprehensive application tips to clarify usage limitations and offering suggestions for combined use based on the potential synergies between principles and patterns.

Finally, it is crucial to establish the potential for continuous updates to the design knowledge booklet. Some participants expressed the need to adapt the design knowledge to different user groups and introduce several unconsidered design principles and spatial patterns. This feedback underscores the importance of presenting the booklet as a dynamic, evolving resource. By clarifying that the booklet is an open-ended tool, practitioners are encouraged to continually update and refine the design knowledge based on accumulating evidence and evolving design intentions. This approach allows the booklet to be personalised and grow into a tailored design tool for individual practitioners.

7.4.3 Limitations

This chapter represents one of the few attempts to assess the usability of design knowledge, providing valuable tools for designers to harness the health benefits of blue spaces and promote a comprehensive understanding of the design process. It also has several limitations, including the subjectivity inherent in the decision-making process of design, biases stemming from the selection of participants, variations in the design experience among participants, and the potential influence of researcher involvement on the outcomes. Firstly, while designers are expected to refer to design knowledge to develop their solutions, the subjective nature of design means that the actual use of this knowledge cannot be definitively confirmed. Although frameworks like the ASE paradigm and various design research approaches portray the design process as a systematic search for solutions after synthesising diverse information, there remains a pressing need for ongoing experimentation to continually assess its applicability and effectiveness (Nijhuis & Bobbink, 2012; Nijhuis & de Vries, 2019).

Secondly, selecting participants and their individual design experiences could influence the effectiveness of the study's findings. This research primarily involves master's students and PhD candidates from the Faculty of Architecture and the Built Environment at TU Delft in the design workshop. While efforts are made to include participants from diverse professional backgrounds, the exclusion of broader segments of the design community, such as established designers and policymakers, may have impacted the precision of the results. On the other hand, while all participants are recruited from TU Delft, ensuring a certain homogeneity in their educational backgrounds, individual differences in design experience can lead to significant variations in how design knowledge is applied. These discrepancies can impact the outcomes of the study. Nonetheless, this diversity of experience also enriches the research by providing a broader understanding of how design knowledge may be applied across different practitioners, highlighting its adaptability.

Third, the involvement of researchers in the workshop could potentially influence how participants apply design knowledge. As organisers of the workshop, researchers assist by explaining processes, reminding participants of procedures, observing design sessions, and providing necessary support. However, in real-world settings, researchers typically do not aid practitioners during the design process. Therefore, the presence of researchers in the workshop might simplify the participants' understanding and application of design knowledge, which does not accurately reflect the independent application in actual practice.

Considering these limitations, future efforts should focus on promoting the widespread application of design knowledge in spatial practice. This entials inviting a more diverse array of practitioners to engage with it actively and further explore its potential as a communication tool among multiple stakeholders. Additionally, given that design knowledge is constantly evolving, it should inspire practitioners to continuously refine and expand it throughout its application, fostering a dynamic tool that effectively adapts to the changing needs of design practices.

7.5 Conclusion

To illustrate and assess the design knowledge derived from the first two parts of the thesis, a design workshop was employed as part of the response to research question 3. The design workshop conducted by the TU Delft teams generated a rich set of quantitative and qualitative data, which is instrumental in evaluating and enhancing the content of the proposed design knowledge. Although workshop participants find the design knowledge generally useful and easy to use, they also provide valuable suggestions for its enhanced application. Based on on-site observations and a comprehensive analysis of participant feedback, this chapter summarised the insights related to using design knowledge, recommendations for future enhancements, and reflections on the current research. Looking ahead, design knowledge should be more broadly implemented in practice, with continuous refinements to promote its effectiveness as a useful tool for a diverse range of practitioners.

8 Reflections on Integrating Public Health Benefits into Spatial Design from Multidisciplinary Experts

This chapter further elaborates on research question 3. Specifically, it investigates how and by what means designers incorporate the health benefits of blue spaces, or more broadly, natural environments, into their daily design practice. It also discusses whether the currently available design knowledge has the potential to become part of the design tools used to implement these health benefits. Semi-structured open-ended interviews are organised to explore this topic, involving active interpretation of the implementation methods and potential design tools respondents reported using and anticipated using to achieve health benefits. The study presents respondents with typical examples of the design principles, spatial patterns, and evaluation methods proposed in this research, along with a brief interpretation of the whole research project. This introduction aims to demonstrate how to use this design knowledge to help implement the health benefits of blue spaces. Six respondents, representing designers, government officials, and academic researchers, participated in a comprehensive discussion and reflection on the study's content. They examined two key aspects: the implementation of broad health benefits in spatial design and the applicability of the currently developed design knowledge. Additionally, they provided insights and expectations for future research in this field.

8.1 Introduction

According to the International Federation of Landscape Architects (IFLA), landscape architects integrate the environment and design – art and science. They plan, design, and manage natural and built environments, applying aesthetic and scientific principles to address issues such as ecological sustainability, landscape quality and health, collective memory, heritage and culture, and territorial justice (IFLA, 2020). Consequently, in practice, designers must develop creative solutions based on site-specific information to meet multiple objectives and achieve diverse benefits.

With the growing requirements and objectives of spatial interventions, the scientific understanding of the design process and the demand for design-assisting tools are becoming increasingly important. Numerous studies have explored and illustrated the design process and proposed various design tools (Liu & Nijhuis, 2020; Nijhuis & de Vries, 2019; Zhang et al., 2023a). Accordingly, this study focuses on integrating blue space and health based on existing knowledge, aiming to develop design knowledge that fulfils the health benefits of blue spaces, thereby providing a valuable tool for designers in their practice. In Parts I and II, including Chapters 2–6, the thesis summarised and proposed relevant design knowledge through a worldwide precedent analysis and case studies of Rotterdam. In the previous chapter, the application of the proposed design knowledge in design processes was examined and evaluated using the workshop methodology. However, as noted in the limitations of the previous chapter, the feasibility of this design knowledge in everyday design is equally important. Unlike the design workshop, the daily design process involves many additional considerations, such as the realisation of design intentions, the integration of different goals, the designer's personal experiences, individual attitudes, and local building regulations. To better understand the tools landscape practitioners use in their daily work to assist in design decision-making and how they plan to implement current design knowledge and health benefits more broadly in future spatial practice, it is essential to reinforce previous research findings. Engaging with practitioners and exploring their perspectives on design knowledge could provide valuable insights into its relevance and application in everyday practice.

8.2 Data and Methods

To achieve the objective and build upon previous research, this chapter conducts a practical investigation into the utility and professional attitudes towards the proposed design knowledge in this study. A semi-structured, in-depth interview method is utilised to gather information and facilitate discussions with experts from various fields. These interviews aim to explore the role of practical knowledge in bridging different discourses across professional boundaries.

8.2.1 Interview Objectives

Through interviews, the study explores experts' perspectives on public health as a spatial design objective, their views on the role of design knowledge in supporting spatial practices in their daily work, and their insights into how various types of design knowledge can effectively influence the development of design decisions. To guide this research, two specific goals are established to frame the overall interview structure, which are:

- **Objective 1**: Each interview explores how practitioners integrate public health benefits, particularly those derived from natural environments, as objectives in spatial interventions, as well as the effective tools needed and the challenges and limitations encountered during implementation phase.

- **Objective 2**: Each interview discusses the application potential of design knowledge generated in this study to daily spatial practices and identifies potential implementation limitations.

8.2.2 Profiles of the Interviewees

Six interviewees are selected on the basis of recommendations and their reputation as reflective practitioners from different branches of spatial design. Participants are requested to articulate their perspectives on integrating public health into spatial design practices, identify potential tools that could facilitate this integration, provide feedback on existing research outcomes, and offer recommendations and projections for future studies or practices. Given that the discussion primarily centres on interpreting and understanding spatial design tools and processes, suitable interviewees typically possess design-related backgrounds or are familiar with pertinent knowledge. Additionally, recognising that the design process typically involves interactions among multiple stakeholders, three distinct groups of respondents are included: two from design companies (one specialising in urban design and the other in landscape design), three from universities and research institutions (with expertise in urban studies, human geography, and public health, respectively), and one representative from the Rotterdam government (Table 8.1).

TABLE 8.1 Occupational Background of the Interviewees.

Interviewee	Occupation
Interviewee 1	– Landscape architect from a professional office – Chief partner of a landscape architecture office
Interviewee 2	– Urban designer from a professional office – Chief partner of an urban design office – Professor of Urban Design at TU Delft
Interviewee 3	– Professor of Urban Studies at TU Delft – Professor of Environmental Behaviour and Design
Interviewee 4	– Senior social scientist at Wageningen University – Environmental psychologist
Interviewee 5	– Assistant professor of social epidemiology in Erasmus MC
Interviewee 6	– Adviser of water management in the Municipality of Rotterdam

8.2.3 Interview Design and Analysis

To articulate professional thoughts and knowledge effectively, ethnographers often employ unstructured or semi-structured, open, and in-depth interviews (Liu, 2020). These interviews facilitate extended conversations between the interviewer and a subject or group of subjects, enabling a comprehensive exchange of visions and explanations. Given the distinct topics of this research, a semi-structured interview guided by specific themes in an open-ended format is deemed most suitable for obtaining interpretive results based on the experts' daily work experiences. A set of planned questions facilitates the natural flow of the interpersonal exchange, allowing the conversation to remain open to interpretation.

TABLE 8.2 Interview Questions.

Part I Opinions on Integrating Public Health Benefits in Spatial Planning and Design	
Question 1	Reviewing your experiences, have you actively linked public health with spatial planning and design in your projects or practices? If so, could you elaborate on their specific details, indicating the types and scales of projects involved? Please provide some examples.
Question 2	Given your extensive experience in academic research related to blue space and health, could you share your insights on the practical applications of this knowledge? Additionally, in your perspective, do you consider these aspects significant for future urban planning and landscape design?
Question 3	To potentially integrate the public health benefits of natural environments or blue spaces into real urban planning projects and spatial interventions, what tools do you believe are essential and needed?
Question 4	What challenges and constraints do you believe when attempting to implement the health benefits of natural environments or blue spaces, or more broadly, public health–related design objectives in practical projects?
Part II Design Implementation of Proposed Design Knowledge	
Question 5	Based on the evaluation methods, design principles, and spatial patterns I have just shown in the files, do you think they can be used as references for designers to fulfil the health benefits of blue spaces in practice?
Question 6	Do you find the design principles and spatial pattern format (examples as shown below) appropriate for practical design applications? If yes, at which stage will you use the principles and patterns during planning or design? If not, what alternative format do you believe would be more suitable?
Question 7	Could you please share your opinions on the translated design principles and spatial patterns? Additionally, do you have any suggestions for enhancing them further?

Each interview commences with an overview of the research topic, objective, and the purpose of the interview. At the outset, information regarding each individual's professional background, such as educational qualifications and relevant work experience, is collected. To fulfil the objectives of the interview, questions pertaining to two main themes (as outlined in Table 8.2) are posed to facilitate discussions and stay on track. Initially, respondents are questioned about their experience integrating public health and spatial design within their daily research and practice. Where applicable, they are asked to provide detailed information about specific projects and to describe the methods employed in those projects. Next, respondents are questioned about their experience with integrating the health benefits of blue spaces or urban natural environments into spatial design. They are also invited to discuss what tools might be necessary and what potential limitations could arise when incorporating the health benefits of blue spaces into design practices, drawing on their previous experiences.

Respondents are then shown selected examples from the study (Figure 8.1), including typical design principles, spatial patterns, and evaluation methods, to illustrate how this design knowledge could serve as a practical tool in harnessing the health benefits of blue spaces within spatial design practice. Subsequently, through the questions in the second part, an open discussion is initiated to explore the application potential of the provided knowledge and to reflect on the shortcomings of current research.

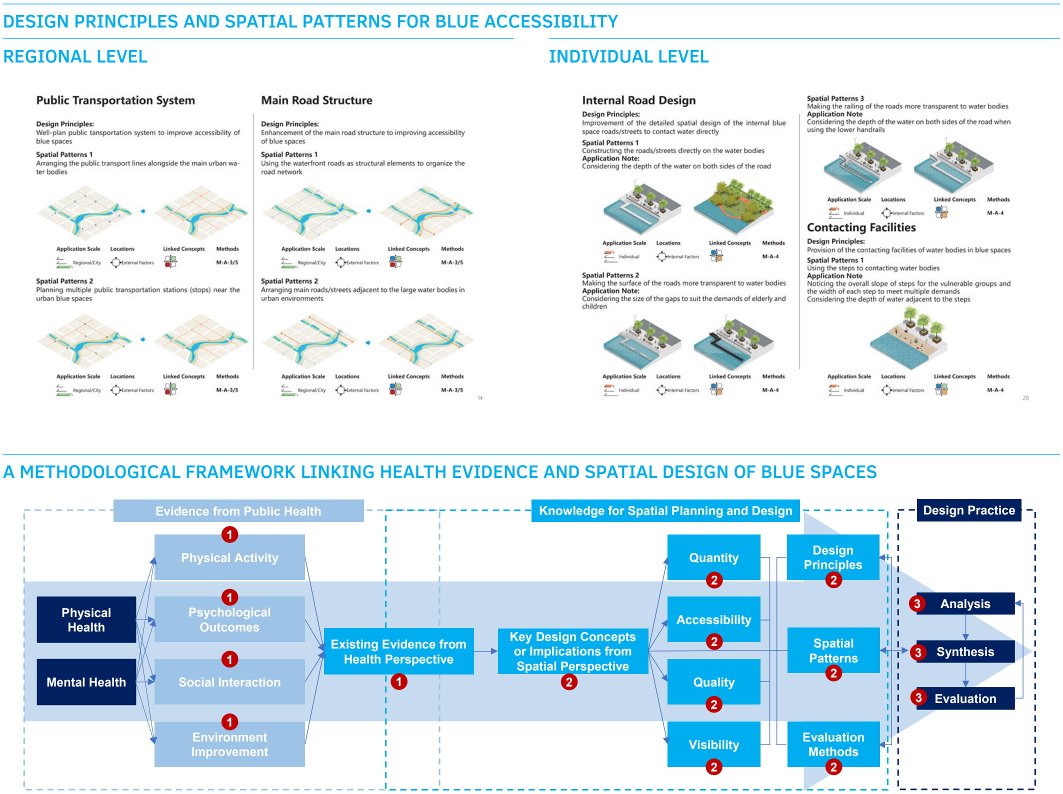


FIG. 8.1 Selected Design Knowledge and Core Research Framework Shown to the Interviewees.

All interviews lasted one to two hours between March and April 2024 and were tape-recorded with the participants' permission. Discourse analysis is employed to analyse and summarise the conversations, facilitating deeper understanding through targeted questions during the interviews and thoughtful reflection during transcription. This approach aims not at uncovering absolute truths but at understanding how conversations evolved into broader discourses (Secor, 2010). Interview transcriptions are coded using condensed analysis to extract key themes and points by meticulously replaying and analysing each in-depth interview and then summarising the highlights.

8.3 Results

8.3.1 Experience in Integrating Health Benefits into Spatial Design and Planning

During the interviews with the experts, the first two questions concentrate on experts' practical experiences, inquiring whether they had ever considered health as an objective in spatial interventions and, more specifically, whether they had incorporated the health benefits of the natural environment into their spatial practices. Surprisingly, most experts report that they had worked on projects where public health was a primary design objective, properly integrated with spatial interventions. These projects not only involve spatial interventions but also delve into evidence explorations, highlighting multidisciplinary interactions.

The focus of these projects is primarily at the individual and neighbourhood levels. According to experts' feedback, this focus can be attributed to two main issues. First, the health impacts of the urban environment are often directly perceived and experienced by individuals, making interventions and observations at the individual level more tangible. Second, current methods of evidence collection and analysis tend to concentrate on the neighbourhood level, which is widely recognised in health-related studies and suitable for implementing spatial policies.

'We've always looked at the more direct living environments of people, not on a city scale, but more on the immediate surroundings of individuals'. (Researcher of public health)

'The projects are mostly done at the individual level… It's meant at a higher level where you don't look at the individual level but at the health of the people within a neighbourhood'. (Researcher of geography)

'On a bigger scale, when the map is called green, you don't know what type of green and if it's really green. In Randstad, from the satellite photo, the city is perceived as green, but it's all glass houses, so it's not really a friendly environment'. (Professor of urban studies)

During the implementation of public health in spatial projects, several experts note that integrating measurable elements and indicators is more feasible. This measurability can be articulated in two distinct aspects: (1) the correlation between specific spatial indicators and health outcomes (such as the association between urban heat and mortality rates) and (2) the relationship between spatial interventions and spatial indicators (such as the influence of vegetation quantity and patterns on urban temperature; see also Ballester et al., 2023; Wong et al., 2021). Experts most frequently mention indicators related to air pollution, urban heat, and traffic conditions. These indicators can be directly associated with public health in design practice, facilitating the incorporation of health considerations into spatial interventions.

'Our group have a long-standing research line on air pollution and health. Reducing air pollution is beneficial for both climate and health, exemplifying the co-benefits of addressing environmental issues. Heat stress, although more a result of climate change than a direct cause, also has a significant impact on health'. (Researcher of public health)

'I always, in teams most of the time, did some research on elements of public health, mainly on some measurable aspects, for instance, microclimates and issues like the heat island effect'. (Professor of urban studies)

'And what we did is that we tried to explain what the actual benefits of NBS (nature-based solutions) are, one of them being the health benefits. For example, with forests, there's insulation and other benefits, but what are they actually?' (Landscape architect)

When examining experts' experiences with integrating the health benefits of natural environments into spatial interventions, there appears to be a divergence in opinions. Practitioners, including urban designers, landscape architects, and policymakers, generally view the health benefits of the natural environment as secondary, often treated as an added value rather than a standalone objective in spatial interventions. Conversely, experts with academic backgrounds are generally familiar with the nature-health nexus, usually drawing from their previous projects to underscore the necessity of interdisciplinary collaboration in this field. Interestingly, some experts distinguish between the health benefits of blue and green spaces, highlighting potential considerations that might influence their integration into practices.

8.3.2 Practical Tools and Existing Limitations for Linking Public Health and Spatial Design

Considering integrating health benefits, particularly those derived from natural environments, into design practices, experts have delineated three distinct categories of tools. A professor in urban studies highlights their approach of incorporating public health principles into design education, endeavouring to sensitise students to the health implications of urban environments. This pedagogical strategy contrasts with the current study's focus, which has admitted the health benefits of natural environments in advance. Instead, the professor challenges students to investigate and articulate which types of spaces can foster health benefits based on their own observations. This educational approach avoids the provision of pre-packaged design knowledge, favouring a dynamic process wherein students engage in continuous exploration and synthesis, starting from a foundation of universal design principles. Students progressively internalise their knowledge through this method, transforming it into personal design tools and intuitive insights.

The expert from the public health domain endorses this approach, asserting that such granular, observational evidence is indispensable and can substantively bolster practices, especially since traditional evidence at the community or city level frequently encounters implementation challenges. Furthermore, the respondent emphasises the critical importance of interdisciplinary collaboration in increasing health benefits through spatial interventions, especially the inclusion of researchers specialising in spatial design.

'For design courses... you need to have the literature background information concerning the topic. Together, that often leads to conducting observations or interviews. When there are many different resources available, sometimes we – or I – help the students create design guidelines or patterns to organise their work.... Sometimes, part of the design patterns are more generic, and then you make a specific interpretation in design. And, of course, the patterns are also there to organise the work because every pattern is a relation between research and design. Every pattern can be based on different resources, your own observations, or those from others. So, you can mould everything into the same format, which gives you a better overview. This is particularly helpful for a beginning designer to have that type of overview'. (Professor of urban studies)

'There is a shift happening in the type of evidence being collected. Historically, much of the evidence has been cross-sectional, showing that people living in greener environments tend to be healthier. However, this doesn't necessarily mean that increasing green space will make people healthier.... Observational research and quasi-experimental designs are becoming more common. These methods, along with longitudinal studies, allow us to approach causality without needing controlled experiments'. (Researcher of public health)

On the other hand, the two experts highlight that furnishing robust evidence and formulating evidence-based norms are crucial for harnessing the health benefits of natural environments. Contrasting with the individual-level observational evidence previously discussed, the evidence referenced here encompasses macro-quantitative data spanning the entire continuum, including the relationships among health outcomes, blue-green spatial characteristics, and spatial interventions. This type of evidence plays a pivotal role in supporting the development of urban policies and visions. It also provides a clear, intuitive demonstration of health benefits to policymakers, thereby facilitating their leadership in balancing these benefits against other considerations.

Similarly, experts in geography contend that beyond the collection of evidence, there is a crucial need to develop specific norms that facilitate the implementation of health benefits associated with blue-green spaces. An example of such a norm is the '3-30-300' guideline, which is presently gaining substantial attention (Konijnendijk, 2023).

'To make public health a priority, we need to show that it's at least as important as other concerns. Right now, anything with a quantifiable metric often wins because you can clearly demonstrate the financial or logistical impact'. (Landscape architect)

'We talked about the 3-30-300 guideline. The Municipal Green Space Department, which manages the green spaces, would love it if that became not just a guideline but something they are obliged to adhere to as a norm. A guideline is something you can follow or deviate from. It's not because they think the 3-30-300 is perfect or completely evidence-based. No, but if it's a norm, they have a position at the table in planning processes'. (Researcher of geography)

Additionally, compared to the broader recommendations by the two experts quoted above, the tools deemed more specific by policymakers and urban designers involve nuanced approaches. From a policymaking perspective, projects of natural environments normally need to align with multiple objectives, with health benefits being one potential goal. To effectively integrate these benefits during the project implementation stage, it is essential to equip policymakers with specific analysis and evaluation methods. These methods should be capable of assessing the multi-category benefits of potential solutions and provide substantial support in the formulation of policies. The expert from urban design articulates their support for the significance of evaluation methods, emphasising the benefit and necessity of a comprehensive and transparent framework. This framework could extend beyond evaluation methods to encapsulate the spatial elements that practitioners need to address, specify the content of interventions, and outline the potential benefits of these interventions. Unlike the landscape design expert, who advocates for quantitative connections, the urban designer does not stress the quantitative or qualitative attributes of the framework. Instead, the focus is on how the framework can aid practitioners in elucidating the connections between spatial interventions and the health benefits of blue-green spaces during the solution generation stage.

'From a policy perspective, in order to develop effective policies, we use methods based on models and data… We typically use models to develop policies, but when translating these policies for designers, we must provide them with the necessary tools. They need inspiration to visualise and implement these policies effectively'. (Government adviser)

'These assessment frameworks are very quantitative, whereas the description of health benefits is very qualitative. So, we cannot easily prove these benefits. It would be really good if we could say that by implementing certain solutions, we indeed create a healthier environment and provide an integral framework'. (Professor of urban design)

Reflecting on the comments on existing blue-health research and practices, several experts have voiced concerns about the challenges in implementing the health benefits of natural environments. As previously emphasised, a recurring theme among many experts is the importance of collecting comprehensive health evidence. This evidence encompasses both micro-observational data from specific populations, which is crucial for generating direct spatial interventions, and macro-level public health benefit measurements. The latter is particularly valuable for quantitatively illustrating the health benefits of blue and green spaces, thereby supporting a more informed allocation of discussion and decision-making power in policy negotiations.

Some experts stress the importance of actively implementing the health benefits in policies and spatial interventions, arguing that it is insufficient to merely explore the health benefits of blue-green spaces at a theoretical level. Concrete actions are necessary to comprehend their true impact and to facilitate broader implementation. In many instances, the development of norms may not strictly rely on an exhaustive collection of evidence. Furthermore, several experts have suggested that aligning the health benefits of blue-green spaces with other, more quantifiable or currently prioritised objectives – such as climate adaptation, biodiversity enhancement, and air quality improvement – could be an effective strategy. This integration not only makes the health benefits more tangible but also elevates the significance of blue-green spaces in policy discussions. By tying these spaces to multiple objectives, policymakers are more likely to recognise their multifaceted value, thereby establishing a stronger foundation for creating norms and policies.

8.3.3 Reflections on the Proposed Practical Design Knowledge

Experts generally provide positive feedback on the design knowledge proposed in this study, but they also offer personal insights and suggestions for improvements from various perspectives. Regarding the content of design principles and spatial patterns, most experts found them to be straightforward and comprehensible, offering multiple options suitable for different cases. However, they also proposed enhancements in three key areas: (1) principles and patterns should be adaptable to various application scenarios, particularly in less affluent neighbourhoods; (2) developing these principles and patterns should account for the diverse uses and perceptions of different demographic groups, emphasising cultural sensitivities and the needs of vulnerable populations; (3) some principles and patterns are relatively basic, suggesting that their specificity and detailed application guidance should be enhanced.

‘This could be quite useful because it would provide something that designers can’t do without this tool. While this is basic design knowledge, providing designers with new information could help them make more informed design decisions’. (Professor of urban design)

On the other hand, experts share varied opinions on whether to illustrate connections between different design principles and patterns. Generally, they appreciate the organisation of these principles and patterns by scale and type of spatial elements, which they believe offers designers a clearer and more specific framework. Many experts suggest that future improvements should address the connections between principles and patterns, including potential synergies and trade-offs. However, some argue against emphasising these relationships, believing such suggestions might limit designers’ creativity and ability to tailor principles to specific site conditions.

TOC

Additionally, like feedback from workshop participants for principles and patterns related to improving the quality of blue space, experts also believe that the novelty of the method and the focus on different groups in evidence translation are worthy of recognition. However, some experts note that not all design principles require evidence-based translation, underscoring the value of integrating common sense into design knowledge to enhance its richness and applicability.

'Of course, always mention the relation. If you use this pattern, have a look at this one. Most of the time, it's from the higher scales to the lower scales. There is a relation between one or the other, and sometimes, you can even point out conflicts. If there's this one, then that one is not an option anymore'. (Professor of urban studies)

Most experts agree that the evaluation methods provided in the design knowledge are crucial for practical applications. They see the primary benefits of these methods in two ways: firstly, their advanced nature aids practitioners in making informed, scientific decisions; secondly, they facilitate multifaceted communications. However, experts also suggest areas for future enhancement of these evaluation methods: (1) strengthening the direct linkage between the evaluation methods and health outcomes to ensure more targeted impacts; (2) enriching the parameters available for more detailed simulations and encouraging the integration of current methods with other tools to provide more comprehensive support for practitioners.

'Yeah, not about the designers. That's more about public awareness. This is similar to what we did before, which was to improve residents' awareness about the possible risks of flooding. These visualisations can help make the public aware of the health value of blue spaces. So that's about communication, giving them information, and creating public awareness'. (Government adviser)

8.4 Discussion

8.4.1 Integrating the Health Benefits of Blue Spaces into Spatial Planning and Design

Based on expert interviews about integrating the public health benefits of blue-green spaces with spatial design, four key insights that are of particular concern emerge, including the growing emphasis on quantitative evidence, the unneglected evidence collection at the individual level, the implicit nature of public health objectives, and the dynamic relationship between evidence and practice.

The growing emphasis on quantitative evidence. Despite numerous studies establishing frameworks and providing empirical evidence for urban areas, several experts highlight a significant gap in quantitative evidence regarding the health benefits of blue spaces. The scarcity of research evidence on the health benefits of blue spaces manifests in three distinct aspects. Firstly, while current studies primarily explore the positive and negative effects of various blue space characteristics on health, the threshold levels for these effects remain unexplored (Bratman et al., 2019). Emerging machine learning and nonlinear models offer the potential for more accurately delineating the relationship between blue space characteristics and health outcomes (Xu et al., 2024). Secondly, although current research employs diverse indicators to describe health benefits, including those related to physical and mental health, there is a noticeable gap in linking these to specific, quantifiable health outcomes. Some studies have begun to quantify these health benefits financially, yet such efforts are insufficient (Bowen & Lynch, 2017). Lastly, the heterogeneity of evidence – stemming from cultural differences and an incomplete consideration of spatial elements – hampers the translation of findings into unified strategies and norms. Often, unaccounted and confounding variables not only affect the intensity of health benefits but may also alter the direction of their impact.

The importance of evidence collection at the individual level. While robust quantitative evidence serves as a foundation for formulating general norms, individual-level explorations offer direct, practical assistance. There are three main benefits of individual-level analysis over macro-quantitative evidence. First, it allows for an understanding of the specific needs of diverse groups, particularly vulnerable populations, such as preferences for different exercise facilities in blue spaces, as highlighted in Chapter 6. Second, individual-level evidence requires less extensive data and, unlike the extensive data and workload needed to translate macro evidence into norms, it can incorporate cultural and contextual factors, providing localised support for crafting targeted spatial interventions. Finally, because individual-level evidence is site-specific, it avoids the challenges of heterogeneity that large-scale quantitative studies face, enabling quicker translation into practices. Overall, individual-level evidence complements large-scale quantitative data collection, offering designers a basis for intervention where current quantitative evidence is lacking.

The implicit nature of public health objectives. Many experts have noted that the health benefits of blue-green spaces, while important, are insufficient to serve as the primary objective in current design practice, largely due to their subsidiary nature. Health benefits are often described in ambiguous and general terms, which hinder their ability to stand as a central design objective like more concrete concepts. Such descriptions lack clear indicators that could attract decision-makers or resonate directly with the public, limiting their effectiveness in guiding design priorities. Second, the health benefits of blue-green spaces often intersect with other design objectives, which can dilute their prominence as standalone goals. For instance, the temperature regulation provided by blue spaces not only offers direct health benefits by mitigating heat stress but also aligns with objectives like combating climate change and reducing urban heat island effects. Third, practitioners often integrate strategies for attaining health benefits into broader spatial interventions. For example, objectives like enhancing urban vitality and inclusiveness often guide urban public space planning and design projects. In executing these goals, designers commonly utilise blue-green spaces to foster public activities, thereby indirectly achieving health benefits through these broader objectives.

The interactions between evidence and practice. The relationship between evidence and practice in design is typically envisioned as one-directional: sufficient evidence collection underpins the formulation of spatial intervention strategies, which is the centre of the evidence-based design paradigm. However, this idealised model frequently entails practical challenges that necessitate adaptive adjustments. In many instances, practitioners cannot wait to collect comprehensive evidence before intervening, especially when addressing complex urban issues. Hence, the importance of feedback in the implementation of blue-green space health benefits cannot be overstated. The interaction between evidence and practice should be viewed as a dynamic process that requires continuous optimisation and adjustment. Active practice clarifies the evidence, while design thinking enables the proposal of solutions that, although not perfect from an academic standpoint, are crucial for timely interventions. Close collaboration between researchers and designers is essential to ensure that spatial interventions are both evidence-based and practically feasible.

8.4.2 Roles of the Proposed Knowledge in Spatial Design Practices

According to feedback from experts, the design knowledge proposed for implementing the health benefits of blue spaces in spatial design practice supports practitioners in three key ways: (1) providing designers with practical references, (2) offering policymakers management and communication tools, and (3) enhancing public awareness and participation.

Practical references for designers. Design principles and spatial patterns serve as essential references for designers, particularly in inspiring creative solutions as analysed in previous discussions of the design process. It is important to note that for experienced designers, the value of these principles and patterns may be somewhat limited due to their extensive experience and finely honed design intuition, allowing them to conceptualise designs rapidly. However, for novice designers and students, these principles and patterns are incredibly valuable. They provide a foundational overview of design strategies, which can be internalised and transformed into personal design experiences through practical application.

Inspired by Liu & Nijhuis's (2021) insights on spatial-visual mapping methods, the evaluation methods outlined in this study can also function as practical design tools. Notably, many of these methods are grounded in quantitative analysis and are capable of delivering real-time results. They offer a significant advantage over traditional methods that depend on subjective evaluations, providing designers with more precise scientific insights to understand site characteristics and guide the development of spatial interventions.

Management and communication tools for policymakers. The government expert highlights how design knowledge serves as an effective communication tool among policymakers, multiple stakeholders, and designers. This tool's utility is two-fold. First, as previously noted, the evaluation methods in the design knowledge enable the simulation of potential scenarios, assisting policymakers in decision-making through engagement with various stakeholders. Second, the design principles and spatial patterns within the design knowledge, particularly visually expressed ones, facilitate communication between policymakers and designers. Often, policymakers are tasked with translating abstract concepts and requirements into actionable policies. In such instances, these visual expressions become crucial tools for negotiating and communicating with designers throughout the policymaking process.

Communication tool for improving public awareness and participation. In Chapter 3, the methodological framework of evidence translation revealed the role of design knowledge in enhancing public participation. This support manifests in two primary ways: (1) menu-based design principles and spatial patterns provide a platform for the non-professional public to engage by selecting their preferred options, thereby actively participating in the design process; (2) visual and real-time evaluation methods facilitate public understanding and the comparison of different spatial interventions, laying the groundwork for multi-party communications. During interviews, experts recognise these insights and suggest that visual patterns could effectively raise public awareness. This form of visual expression intuitively communicates the health benefits of blue spaces to the public, fostering their incorporation into practical interventions.

8.4.3 Recommendations for Future Research and Practices

Based on experts' reflections and suggestions derived from an extensive examination of nature-health research and existing findings, several valuable directions for future research and practice have been identified. First, future investigations should deepen the understanding of the relationship between blue space and health by focusing on the collection of quantitative evidence. This approach will help translate findings into measurable outcomes, thereby solidifying their role in navigating trade-offs between different objectives and aiding in establishing relevant norms. Additionally, local evidence collection at the individual level is crucial as it provides actionable insights that directly support practitioners.

Second, a comprehensive economic evaluation of the health benefits derived from blue spaces is essential. This analysis should comprehensively consider both the costs derived from health benefits and those associated with the implementation and ongoing maintenance of blue space interventions. Such an economic perspective will enable policymakers to assess the value of health-oriented blue space interventions more effectively and make more informed scientific decisions.

Third, future research and practice should aim to develop a more comprehensive framework that integrates the health benefits of blue-green spaces with other values they provide, offering robust methodological support for practitioners. This framework should encompass not just evaluation methods for the diverse benefits of blue spaces but also practical spatial intervention strategies and recommendations.

Fourth, while most experts currently see no need to mandate the use of specific connections and combinations of design principles and spatial patterns – preferring to maintain flexibility – future studies could include guidance on potential incompatibilities between different principles and patterns to avoid practical conflicts.

Lastly, experts have offered several specific and detailed suggestions for future enhancements to the proposed design principles and spatial patterns. These include minimising irrelevant spatial elements in visualisations to improve clarity, providing targeted suggestions for applying design knowledge in specific contexts, and ensuring that the design principles are adaptable to different populations – particularly more vulnerable groups.

8.4.4 Limitations

This chapter explored the integration of public health objectives into spatial design practices, specifically focusing on the health benefits of blue spaces through interviews with six experts from diverse backgrounds. While the insights provided by these experts are invaluable for highlighting current research dilemmas, identifying potential tools, evaluating existing research outcomes, and suggesting future research directions, the study still has some limitations.

First, the study includes only 1–2 experts from each field, chosen to maximise the diversity of perspectives and capture a wide range of stakeholder views. However, this small number per category could potentially introduce biases in their responses. Although the study mitigates this issue by selecting highly experienced experts, future research should consider increasing the number of interviewees and broadening the range of expert backgrounds to validate and refine the conclusions drawn here.

Secondly, the study presents only a portion of the proposed design knowledge to the experts for consultation, potentially leading to an incomplete recognition of its limitations. To mitigate this, researchers presented a summary and a comprehensive booklet of all design knowledge to the experts before the interviews and provided hard copies of all materials during the sessions for continuous reference. Despite these efforts, the extensive nature of the content may still hinder the interviewees from thoroughly reviewing it. Therefore, future research could enhance this process by utilising the application results of the design knowledge as supplementary material and conducting multiple follow-up interviews.

Finally, to maintain focus during the interview, the duration was limited to 1–2 hours, which inherently restricts the depth of content concerning experts' personal opinions. For instance, experts are only asked to provide two or three of their most impactful examples from past research and practices, which could restrict the potential for more extensive discussions. Additionally, the brief nature of the interview content necessitates reliance on manual coding and summaries for analysing the transcripts. In the future, extending the interview duration through multiple sessions could allow for a more comprehensive data collection approach. This expansion could also enable the application of advanced analytical methods, such as word frequency analysis and machine learning–based theme extraction, to achieve a deeper and more nuanced understanding of the interview outcomes.

8.5 Conclusion

This chapter, in conjunction with the design workshop discussed in the previous chapter, aimed to address research question 3 by exploring the potential for integrating the proposed design knowledge into blue space design practices. The prior chapter demonstrated the practical application of design knowledge through design experiments in a workshop, evaluating its potential for real-time design processes. This chapter built on that foundation by interviewing several experts from diverse fields, each offering their assessments of the usability and effectiveness of the design knowledge from their unique perspectives.

Significantly, discussions with these experts encompass broader topics such as the potential, methodologies, and challenges associated with integrating public health objectives with spatial design. The interview results reveal that while most experts have experience incorporating health benefits into their research and practice, there are few projects where health benefits, particularly those derived from the natural environment, serve as the primary target for spatial interventions. The experts also share several reasons for this current dilemma, describe the potential tools required to implement these health benefits in practical settings, and comment on the effectiveness of the existing research findings.

Subsequently, the study distils four main insights based on the expert interviews, including the growing emphasis on quantitative evidence, the importance of evidence collection at the individual level, the implicit nature of public health objectives, and the interactions between evidence and practices. Experts believe that the knowledge proposed in this study can enhance the spatial design process in three key aspects: practical references for designers, management and communication tools for policymakers, and communication tools for improving public awareness and participation. Based on their feedback, a series of recommendations for refining this design knowledge are compiled. Although the interviews yield many valuable insights, attention must still be paid to potential biases due to expert selection and constraints imposed by the content and duration of the interview. Moving forward, it is crucial to continue gathering evidence and refining design knowledge while actively promoting its application in practice. Doing so will allow for ongoing testing of its effectiveness and enable continuous improvement through practical feedback and interactions.

9 Synthesis and Outlook

This chapter offers a discussion, conclusion, and set of recommendations derived from this research. Each sub-question is systematically answered to address the main research question. This response is followed by reflections from general, methodological, and practical perspectives, which include an examination of shortcomings in health evidence explorations, constraints related to methodology or data, and technical limitations. To deal with these challenges, this chapter discusses recommendations for further research aimed at effectively harnessing the public health benefits of blue spaces or natural environments and constructing 'healthy cities'.

9.1 Introduction

This thesis has explored the development of design knowledge to assist practitioners in releasing the health benefits of blue spaces during spatial interventions. The primary motivation for this thesis is the challenge of translating health-supportive evidence of blue space into spatial practices, which is exacerbated by an insufficient understanding and lack of methodological support for the translation process. Addressing existing theoretical and methodological gaps, this thesis systematically analyses the relationship between health evidence and practical applications, endeavouring to bridge them by translating health-supportive evidence of blue spaces into design knowledge for practitioners. Specifically, this thesis integrates evidence analysis, precedent studies, empirical analysis, and design experiments to concretely implement the translation process of health-supportive evidence related to blue spaces. Notably, this study does not aim to deliver fully translated design knowledge but rather to provide methodological support for translating health evidence and a nuanced understanding based on existing evidence. It also acknowledges the limitations of current findings, treating them as 'open-ended' results.

The research begins with a comprehensive overview of existing studies in blue-health research, identifying several prevailing themes and trending topics in current scholarship, as well as a significant research gap, noting the disparity between health evidence and its practical implementation. To address this gap, a methodological framework is proposed to translate health-supportive evidence of blue spaces into actionable design knowledge. This framework, guided by existing evidence collection and analysis, summarises four key spatial design themes of blue space – namely quantity, accessibility, visibility, and quality – for the development of practical design knowledge. Reflecting the subjectivity and objectivity of the design themes, the research delineates two distinct approaches to developing design knowledge. For objective design themes – quantity, accessibility, and visibility – worldwide precedent cases and interdisciplinary knowledge or tools serve as the basis for developing corresponding design knowledge. Consequently, the resultant design knowledge comprises design principles, spatial patterns, and evaluation methods.

In reference to spatial quality, which emphasises subjective experiences, an integrated analysis of the Rotterdam case utilising multi-source spatial quality data and crowdsourced physical activity data underpins the development of tailored design knowledge corresponding to this theme. Subsequently, the design knowledge was applied in a design experiment to assess the usability of the proposed design knowledge and to gather insights for further enhancement based on user feedback. Fifteen participants were invited to join a design workshop by implementing the developed design knowledge at two testing sites on the Delft campus. Additionally, to enhance the robustness of the research, six experts from interdisciplinary fields were interviewed to evaluate the application potential of the design knowledge in practices and to discuss the concerns associated with integrating public health benefits into spatial design, substantiating directions for future research and practice.

This concluding chapter presents a thorough discussion, conclusion, and set of recommendations based on this research. In addressing the main research question, each sub-question is systematically resolved, complemented by reflections on the research, including an analysis of gaps in health evidence explorations, methodological or data constraints, and technical limitations. To overcome these challenges, the chapter proposes recommendations for future practice and research, focusing on effectively harnessing the health benefits of blue spaces or natural environments and fostering the development of 'healthy cities'.

9.2 Answers to Research Questions

9.2.1 Sub-questions 1 (Part I, Chapters 2–3): Research Overview and Methodological Framework

What is the relationship between freshwater blue space and human health from a spatial design perspective?

With the growing prevalence of chronic lifestyle-related diseases, global awareness of health issues is intensifying. Natural environments, critical components of urban contexts, are garnering increased attention as integral elements of public health and urban planning policies due to their significant potential to address these health concerns. However, blue spaces have often been overshadowed by green spaces and have not received sufficient attention for an extended period. Recently, with increased focus on waterfront development and the establishment of interdisciplinary research projects, the public health benefits of blue spaces have regained the attention of researchers and have gradually emerged as a distinct academic field. Therefore, serving as both the breakthrough point and theoretical foundation, this research initially conducts a comprehensive overview of current studies on blue-health research and conceptualises a concise six-step bidirectional framework to connect health evidence of blue space with spatial design practice.

The results indicate that current research primarily focuses on three categories: the mechanisms linking freshwater blue space to human health, the various health benefits associated with freshwater blue spaces, and their connection to global challenges. In recent years, topics such as urbanisation, long-term exposure, and the interplay with green spaces have dominated freshwater blue health research. Notably, three trending topics in this research area include (1) an emphasis on experience and usage, (2) a focus on psychological outcomes, and (3) an examination of health benefits for specific age groups. Supported by the conceptual framework and findings from the review, a significant research gap has been identified: the scarcity of studies exploring blue spaces and health from a design perspective. Such explorations are crucial as they not only provide a foundation for assessing the health benefits of blue space design interventions but also offer practical guidance and knowledge for incorporating the health benefits into the design process of blue spaces.

Building on this foundation, the research progresses with a systematic review of key literature in the field, identifying four main pathways that link blue space and health. Integrating the findings from reviews and refining the initial conceptual framework, a four-step methodological framework is developed, including (1) distilling critical health evidence, (2) summarising key design concepts, (3) categorising the core design themes, and (4) translating them into design principles, spatial patterns, and evaluation methods. This framework aims to connect the health-supportive evidence of blue spaces with design knowledge, facilitating the translation of theoretical insights into practical strategies. Considering the complexity of the design process, the research further discusses the feasibility of the methodological framework through case studies, as well as the potential of the translated results to be applied in real-world scenarios.

Consequently, the methodological framework proves valuable for both practitioners and researchers by providing direct references for design practices, enriching the design toolbox with the accumulation of health evidence, and offering insights for researchers to identify future directions.

9.2.2 Sub-questions 2 (Part II, Chapters 4–6): Practical Design Knowledge

What knowledge and tools can be applied to the spatial design of blue spaces to enhance public health in urban environments?

Practitioners frequently seek design knowledge in their professional activities, which not only offers direct references for developing spatial interventions but also aids them in conceptualising abstract design objectives and facilitating interactions with multiple stakeholders. Following the methodological framework, three types of design knowledge aimed at harnessing the health benefits of blue spaces are developed: design principles, spatial patterns, and evaluation methods. More specifically, design principles and spatial patterns can be regarded as general design knowledge, providing practitioners with direct references to generate site-based design interventions adaptively. Evaluation methods focus on the real-time assessment of potential design solutions, aiding practitioners in decision-making and facilitating cross-disciplinary communications. Based on the meanings of the four design themes outlined in the methodological framework, two approaches for developing design knowledge are proposed. The design knowledge generated through these methods is presented and included as a separate booklet in the Appendix A.

For design themes associated with objective measurements of blue spaces, such as spatial quantity, accessibility, and visibility, the design knowledge encompasses design principles, spatial patterns, and evaluation methods. These are developed based on the types of spatial elements and the scales of spatial interventions specific to blue spaces. The corresponding design principles and spatial patterns are crafted through a combination of worldwide precedent studies and the researcher's design thinking. Conversely, eight distinct evaluation methods for three design themes have been developed and summarised by integrating interdisciplinary tools and knowledge. Rotterdam serves as a test case, illustrating the effectiveness of these methods in assessing the performance of the three themes. These methods evaluate blue space quantity, accessibility, and visibility by employing diverse data types, scale levels, and tools. On the one hand, they offer tool support for designers to evaluate the application effectiveness of proposed design principles and spatial patterns. On the other hand, using these methods in combination can further unlock their potential to address complex urban challenges, providing practitioners with fresh perspectives and additional knowledge.

For design themes associated with the subjective measurements of blue spaces, such as spatial quality, design knowledge – comprising design principles and spatial patterns – is derived from site-specific analyses, acknowledging that spatial quality factors are deeply connected to individual perceptions and experiences. In particular, by utilising crowdsourced data on physical activities and employing a machine learning approach to measure spatial quality, this research investigates the relationships between blue space quality and the level of physical activity at the street level in Rotterdam, the Netherlands, with a specific focus on variations across different activity types and population groups. The results are then used to formulate corresponding design principles and spatial patterns that enhance spatial quality to increase physical activity in blue spaces.

The design knowledge, covering the four types of design themes, has been compiled into a standalone booklet included in the Appendix A, serving as a direct reference for designers in their practices.

9.2.3 Sub-questions 3 (Part III, Chapters 7–9): Design Experimentation and Expert Interviews

How to apply practical design knowledge in blue space design and planning processes?

Although existing research has highlighted the practical potential of design principles and spatial patterns as valuable design knowledge, this study employs design workshops and expert interviews to evaluate the usability of the proposed design knowledge. Fifteen participants, comprising master's students and PhD candidates from Delft University of Technology, engaged in a workshop designed to simulate the application of this design knowledge within an actual design process. The majority of participants found the design knowledge to be generally helpful and user-friendly, demonstrating adaptability during its application, although usability varied across different types of design knowledge. Furthermore, through site observations and post-workshop questionnaires, participants provided suggestions for enhancing the current design knowledge, focusing on improvements in its overall organisation, specific content, and the detailed visualisations employed.

Subsequently, interviews were conducted with six experts from diverse backgrounds, including various design practices, levels of government, and academic fields, to explore the implementation of public health benefits of the natural environment in spatial design and to examine how existing design knowledge might facilitate this process. The findings reveal that while most experts have integrated health benefits into their research and practice, only a limited number of projects prioritise these benefits as their primary objective. Moreover, significant challenges persist in incorporating public health considerations into spatial interventions. The study subsequently distils the main insights and opinions from the experts into four categories and concludes that the current design knowledge could be effectively integrated into design practice across three distinct dimensions.

Overall, while participants from the workshops and experts interviewed expressed favourable views on the design knowledge presented in this study, there remains a need for ongoing application and evidence collection to continue to validate its effectiveness and integrate it into the designer's toolkit. In the broader context of nature-health research and practice, fostering cross-disciplinary collaboration is essential. Such cooperation not only facilitates the collection of more comprehensive evidence but also enhances the understanding of the evidence-practice nexus. Moreover, it amplifies the influence of public health objectives in policymaking and aids in establishing norms, thereby strengthening the integration of health benefits into spatial design practices.

TOC

9.2.4 Conclusion of the Findings

To achieve the main research objective, this thesis provided a methodological framework to link the health-supportive evidence of blue spaces and practical spatial interventions, developed design knowledge based on the framework and evidence explorations, and discussed the practical application potential of the knowledge. A mixed method approach was adopted in which, first, a scoping review and systematic review were undertaken to comprehensively overview the status of blue-health research, identify current research gaps, collect the health-promoting evidence of blue space, and propose a methodological framework translating evidence into design knowledge. Next, according to different spatial themes, the study proposed design knowledge, including design principles, spatial patterns, and evaluation methods, to implement blue space health benefits through worldwide precedent and site-based analysis. Finally, a workshop with hypothetical design experiments and in-depth interviews with experts were organised to validate the research outcomes, discuss the existing situations of integrating health benefits of natural environments in spatial design practices, and look at the future development of this research area in both practice and theory. The conclusions are as follows:

1 Based on the overview of 1,338 publications on freshwater blue-health research, the number of publications in this area has increased rapidly and features broad collaboration among different disciplines. Three main research categories are distinguished: mechanisms linking freshwater blue space and human health, different health benefits of exposure to freshwater blue space, and the relationship with global challenges. Moreover, several keywords, including urbanisation, long-term exposure, and green space, indicate the recent research frontiers.

2 According to the conceptual framework and in-depth analysis of publications, three trending topics in blue-health research are summarised: (1) focusing on experience and usage, (2) attaching importance to psychological outcomes, and (3) paying attention to the health benefits for specific age groups. Simultaneously, the main vacuum in current research is identified as a lack of design exploration.

3 Building upon the analysis of existing health-promoting evidence of blue spaces, four main pathways linking exposure to/contact with blue spaces and human health are outlined: (1) improving ambient physical environments, (2) enhancing physical activity, (3) benefiting psychological outcomes, and (4) promoting social interaction.

4 Deepening the existing conceptual framework, a detailed four-step methodological framework for translating health-promoting evidence into practical design knowledge is proposed, including (1) distilling critical health evidence, (2) summarising key

design concepts, (3) categorising core design themes, and (4) translating them into design principles, spatial patterns, and evaluation methods.

5 Combining existing studies and interdisciplinary knowledge, there are eight predominant methods available and efficient for analysing and evaluating blue space quantity, accessibility, and visibility, including the statistical index approach, spatial interaction approach, spatial-oriented approach, spatial proximity approach, object-based approach, 3D landscape analysis, spatial configurational approach, and segmentation analysis.

6 Considering the distinct features of the various methods, selecting suitable methods could emphasise the design intentions, data availability, spatial scales, and interactions between methods and spatial design processes.

7 Given the evaluation nature of the methods, these eight methods can be actively integrated into spatial design interventions, providing clues for cross-scale interventions, offering the communication basis for multiple stakeholders, and supporting the development of multidisciplinary policies.

8 Employing precedent studies of worldwide cases, the practical design principles and spatial patterns for improving blue space accessibility, visibility, and quantity are proposed. The principles and patterns are organised based on the spatial elements and scales and maintain a certain level of flexibility, enabling practitioners to explore various possibilities in applications.

9 Utilising crowdsourced data and a machine learning approach, the relationships between the blue space quality and the recreational physical activity amounts at the street level in Rotterdam are explored, considering variances among activity types and population groups.

10 Recreational physical activity levels related to street segments vary based on the blue space type and design. Compared to inland canals/rivers, small-scale recreational bodies of water are more conducive to running but not cycling, though both activities tend to cluster around the Nieuwe Maas River. The water view index shows a general negative association with both running and cycling after adjusting for the blue space type. Further, eye-level quality factors, including a higher green view index, lower building density, more diverse land use, a more densely connected street network, and fewer traffic elements, are associated with more running and cycling activity. Results for visual complexity and neighbourhood population composition are mixed depending on the activity type.

TOC

11 The attractiveness of blue spaces for running demonstrates variability, with an observed increase in the clustering of running activities as age progressed, extending beyond urban centres. Factors related to eye-level quality and the built environment significantly influence individual running preferences. Notably, there are distinct differences and spatial heterogeneity in how various spatial quality factors impact running activity across different age groups.

12 Drawing on the research findings from the Rotterdam case studies, tailored design principles and spatial patterns for improving the spatial quality of blue space are developed, informed by age-specific environmental preferences and the diverse requirements of various activity types, contributing to a deeper understanding of the blue-health mechanism and offering practical insights for creating exercise-supportive and health-promoting blue spaces.

13 Participants in the design workshop find the design knowledge generally useful and adaptable, though its usability varies across different design themes. Feedback suggests improvements in the organisation, content, and visualisations of the design knowledge to enhance its effectiveness.

14 There are four main insights distilled from the expert interviews that should be emphasised in future explorations, including the growing emphasis on quantitative evidence, the importance of evidence collection at the individual level, the implicit nature of public health objectives, and the interactions between evidence and practical implementation.

15 The design knowledge proposed in this research could assist practitioners and improve the implementation of health benefits of blue space in spatial interventions in three ways: as a practical reference for designers, as management and communication tools for policymakers, and as communication tools for improving public awareness and participation.

16 In future studies and projects, it is essential to persist in collecting evidence and refining design knowledge while actively promoting its application in practical settings. This approach will facilitate ongoing testing of its effectiveness and foster continuous improvement through practical feedback and interactions.

9.3 Limitations

9.3.1 General Limitations

The health benefits of the natural environment have garnered increasing interest from researchers and practitioners amidst growing health concerns in urban settings. Blue spaces, as a significant component of the natural environment, have particularly attracted attention in recent years. Despite the vigorous pursuit of evidence in this area, there is a crucial need to explore integrating blue space health benefits into spatial practice, which serves as both the impetus and primary objective of this study. Although initial investigations have been conducted, several limitations persist. First, due to the scarcity of existing evidence, the study struggles to establish a definitive quantitative link between design interventions and health outcomes, a challenge also emphasised by several experts. For instance, while ample evidence suggests that the residential visibility of blue spaces positively affects mental health, the specifics of this benefit and the existence of a threshold for improving blue visibility remain unclear.

Secondly, through an analysis of existing evidence, this study identifies four primary design themes (i.e. accessibility, visibility, quantity, and quality) and develops corresponding design knowledge for each. However, due to the inherent complexity of each theme, they have not been comprehensively addressed, especially the theme of quality. This research evaluates the spatial quality of blue spaces primarily from an objective perspective by quantifying the proportion of elements within the field of vision. However, subjective perceptions of spatial quality, such as safety, attractiveness, and beauty, pose challenges when attempting to describe them through the propositional features of elements at eye level. Furthermore, measurable indicators may fluctuate due to various factors, such as seasonal variations, leading to changes in spatial quality. Future research should address the complexities of these design themes and strive to refine the existing design knowledge through continuous exploration. For instance, a human-computer adversarial model could provide the potential to bridge the gap between people's subjective perceptions and the quantifiable characteristics of blue spaces.

Third, to enhance the quality of blue space for realising health benefits, physical activity has been used as a proxy for health, which notably simplifies the concept of health. Although physical activity is often used as an indicator of physical health, this approach narrows the scope of the proposed design knowledge concerning spatial quality. As noted above, enhancing the quality of blue spaces can also foster public interaction, improve ambient physical environments, and yield positive psychological outcomes, ultimately contributing to overall human health. Future endeavours must leverage emerging data and technologies to more comprehensively understand the relationship between blue space quality and its health-promoting effects, thus providing more robust support for practical applications. For instance, analysing real-time public comments on social media of blue spaces can provide valuable insights into their psychological benefits.

9.3.2 Methodological Limitations

The analytical methods employed in this study face several challenges, including aspects of data collection, data processing, and technical skills. During the literature review phase, the study predominantly sources evidence from the Web of Science core collection. It is important to recognise that this scientific literature database does not encompass many design research studies, and newer approaches, such as machine learning-based literature analysis techniques, have not been fully leveraged. In the future, it is essential to expand the range of databases involved and integrate emerging analytical methods to test and refine the current findings. Similarly, while the precedent analysis in this study includes cases drawn from throughout the world, it should not be construed as exhaustive. Additionally, the selection of these cases, based on professional evaluations, objectivity, and representativeness, has been subject to ongoing debate. Concerns persist that such evaluations may not accurately capture the preferences of the general public.

In selecting methods and tools to assess the accessibility, visibility, and quantity of blue space, this study prioritises data availability and user-friendliness, potentially at the expense of methodological sophistication, which might lead to less accurate results. For instance, while digital terrain models and simplified three-dimensional urban models are commonly used, point cloud data can offer more precise visibility analyses at regional and district-scale levels. Nonetheless, the processing and analysis of point cloud data demand significant computational capacities, which may not be feasible in practical contexts. Therefore, while enhancing the accuracy of analytical tools is desirable, it must be balanced with the practical limitations and capabilities of the technology available to researchers and practitioners.

When utilising crowdsourced data to analyse the relationship between blue space quality and physical activities, this study integrates multiple data sources to characterise the quality of blue spaces. However, the methodology employed does

TOC

not account for several potential variables, such as seasonal variations, personal subjective perceptions of the environment, and the organisational characteristics of space, which limit the comprehensiveness of the design knowledge derived from the analysis. Additionally, the anonymisation of detailed user information in the geographic volunteer data of physical activities results in findings that are not explicitly tailored to distinct demographic groups.

The study engages a limited number of participants and experts for design workshops and interviews, providing valuable insights despite the small sample size. However, increasing the number of participants would likely enhance the accuracy of the findings, though it also may pose practical and organisational challenges. A larger participant pool necessitates more complex testing sites and extended workshop durations, potentially complicating the logistics and diluting the focus from the core objective.

9.3.3 Practical Limitations

This study integrates design thinking with exploring the health benefits of natural environments, aiming to investigate the feasibility of applying health evidence on blue spaces in spatial intervention practices. The design knowledge proposed in the research, encompassing design principles, spatial patterns, and evaluation methods, demonstrates significant application potential. It equips designers with tools for site understanding and analysis, as well as direct references for spatial interventions and policy formulation. Despite these strengths, the study acknowledges existing limitations concerning design objectives, the content of design knowledge, and the effectiveness of evaluation methods.

First, the health benefits of the natural environment have garnered increasing attention among researchers and practitioners, with numerous studies delving into this area. However, the actual implementation of these benefits in spatial interventions is often hindered by their generalised and ambiguous definitions, which relegate them to a secondary status rather than a primary focus. For the future, interdisciplinary efforts are crucial to elevate the health benefits of natural environments to a central position in design interventions. This shift will require a concerted push to refine definitions and methodologies from both evidence-based and practical perspectives, ensuring that these benefits are integrally considered and effectively implemented in design practices.

TOC

Second, while this study strives to summarise design principles and spatial patterns as comprehensively as possible through extensive precedent analysis globally and case studies in Rotterdam, the results remain incomplete. The dynamic nature of design and emerging evidence necessitate that these findings be continuously updated and enriched. Practitioners must actively contribute by integrating new evidence and innovative design interventions, thereby ensuring that the design knowledge remains relevant and effective in addressing contemporary challenges.

Third, the evaluation methods currently employed primarily focus on the accessibility, visibility, and quantity of blue spaces across different scales, yet they fall short of correlating these metrics directly with health outcomes. Additionally, while some methodologies borrowed from other disciplines may offer depth, they often require specific knowledge and skills for proper application and interpretation – a challenge this study has attempted to mitigate by selecting user-friendly methods. To overcome these methodological limitations, it is crucial to develop more straightforward tools to measure health impacts directly. Concurrently, educational and research institutions should proactively engage in and promote the teaching of these methods and foster an interdisciplinary approach to broaden the applicability and understanding of these evaluation techniques.

9.4 Recommendations

9.4.1 Recommendations for Design Practices

This study synthesises and critically examines existing research and evidence, proposing a methodological framework for translating health-promoting evidence into practical design knowledge. This approach opens new avenues for practitioners to implement the health benefits of blue spaces effectively. Furthermore, the study thoroughly delineates the entire process of formulating and applying design knowledge, illustrating how evidence-based design knowledge can be applied at various stages of spatial design to enhance its usability. Throughout the research process, several areas have been identified that warrant further development in future spatial practice. These include (1) expanding the scope of evidence collection to ensure a comprehensive foundation for spatial interventions; (2) continuously improving the content of design knowledge to adapt to various contexts; (3) encouraging practitioners to apply the developed design knowledge in their projects; and (4) fostering interdisciplinary cooperation and education.

The current study has identified four main design themes through the analysis of available evidence and has translated the themes into design knowledge for facilitating the implementation of the health benefits of blue spaces. As noted in the limitations, these themes are contingent upon available evidence. Going forward, practitioners are encouraged to dynamically refine the methodological framework through ongoing evidence collection while maintaining the overall structural integrity of the framework. For instance, the theme of spatial quality, although richly addressed in this study, has not been exhaustively explored. Practitioners could further delineate this theme into more nuanced and specific sub-themes to enhance its practical application and effectiveness in future studies.

In addition to ongoing evidence collection, the compilation of design case studies is crucial. These case studies provide a vital source of direct design knowledge. While the existing design principles and spatial patterns are primarily derived from a summary of global precedents, the inherent creativity of designers ensures significant potential for continual updates to these principles and patterns. Consequently, it is essential for practitioners to actively refine and document emerging design cases, using these insights to supplement or revise the current body of design knowledge. This iterative process not only enhances the relevance of design knowledge but also adapts it to evolving challenges and opportunities.

Although this study has, to some extent, validated the effectiveness of the current design knowledge through design workshops and interviews, practitioners must continue to apply it. Such engagement not only serves as a foundation for the further refinement and enhancement of design knowledge but also helps practitioners to integrate this knowledge into their design skills.

Last, for the new generation of designers, possessing traditional design knowledge alone is insufficient. They must also comprehend and master advanced evaluation methods that enable them to identify site-specific problems and assess the outcomes of interventions. As demonstrated in this study, many of these evaluation methods necessitate applying interdisciplinary knowledge and tools. To address this need, it is crucial to foster multidisciplinary exchanges and interactions in the future and to incorporate interdisciplinary knowledge and tools into educational processes.

9.4.2 Policy Recommendations

While the current research emphasises advancing the implementation of health evidence from a design perspective, the influence of urban policies is equally significant. Urban policy development must prioritise public health as a central objective, ensuring it holds parity with other critical agendas. This aim can be advanced through two key strategies in the future: (1) facilitating the incorporation of health evidence into urban policymaking and (2) enhancing public awareness of the health benefits associated with well-designed urban spaces.

On the one hand, implementing public health benefits derived from blue spaces and even natural environments has not been effectively realised in practice. This shortcoming arises partly from the absence of practical methodological guidance, which is a central focus of this study. Additionally, policies often fail to prioritise public health as a core objective within spatial interventions. This oversight may stem from the ambiguous definition of public health goals. Elevating the prominence of public health in policy discussions is a crucial strategy to mitigate this issue. In the future, it is feasible to develop a comprehensive framework that integrates the health effects of spatial interventions in natural environments. Moreover, policies could establish norms that mandate the implementation of health benefits, although developing such norms likely requires robust evidence.

On the other hand, enhancing public awareness of the health benefits of blue spaces can significantly facilitate favourable conditions for policymaking. Typically, policymaking must evaluate the impacts across multiple dimensions, and the health benefits of blue spaces and natural environments might seem limited when translated into economic terms compared to other priorities. However, as public awareness of health benefits increases, there is a greater likelihood that public health considerations will be integrated into policymaking processes, even when the economic advantages of preserving natural environments are less apparent.

9.4.3 Recommendations for Future Research

This study explores the potential of incorporating health-promoting evidence of blue spaces into spatial design, representing an effort to integrate public health into spatial interventions. At this stage, four main developmental directions have emerged: (1) enhancing the comprehensive linkage between blue space interventions and health outcomes to ensure clarity in cause-and-effect relationships; (2) deepening the understanding of the connection between the quality of blue spaces and their health benefits to inform more effective design strategies; (3) refining and expanding the body of design knowledge to ensure it is both precise and comprehensive; and (4) fostering a synergistic relationship between research and practices.

First, while this study has begun to outline a framework linking blue space and public health, the current framework does not fully elucidate the connection between blue space interventions and health impacts. This omission is evident in the inability to concretely define health outcomes associated with blue spaces and the ambiguity surrounding the health results from targeted spatial interventions. Consequently, future research must intensify efforts to collect comprehensive evidence to clarify these connections, thereby providing a robust theoretical foundation for policy formulation and implementation. This extensive evidence-gathering will also necessitate enhanced communication and interaction among researchers and practitioners from diverse professions. Such interactions can bridge gaps between disciplines and leverage their respective strengths. For instance, scholars in public health and geography can contribute rigorous analytical methods to ensure evidence comparability, while spatial design experts can offer insights into the specific characteristics of blue spaces and the nuances of spatial interventions.

In addition to macro-level suggestions for future research, specific limitations identified in this study also merit attention in subsequent inquiries. Specifically, the foundation for the design principles and spatial patterns aimed at enhancing the blue space quality in this study mainly stems from analysing the relationship between spatial characteristics and physical activity. However, this approach is insufficient. First, physical activity alone does not encompass the full spectrum of health, and second, the current characterisation of blue space quality remains in its infancy. Future research should, therefore, build on this groundwork, utilising advanced methodologies and data to deepen the understanding of the relationship between blue space quality and health benefits.

Moreover, the ongoing refinement of design knowledge extends beyond the contributions of practitioners alone; researchers also play a crucial role. They are instrumental in further optimising and enhancing the content of the methodological framework and refining existing design knowledge. For instance, researchers can dynamically adjust the content and scope of design themes based on ongoing evidence collection. Simultaneously, they can incorporate more advanced tools as evaluation methods to enhance the precision of analyses, or they can develop simpler and more integrated methods to lower the learning curve for practitioners.

9.5 Conclusion

This study aims to furnish design knowledge that facilitates the integration of health benefits associated with blue spaces into design practice, thereby exploring the potential of public health as an objective in urban planning and design. This process begins with a comprehensive review of current research evidence, followed by constructing a methodological framework linking health-promoting evidence with spatial practices. Subsequent steps include the development of practical design knowledge for creating healthy blue spaces, incorporating this design knowledge into design processes, and critically investigating the reflections on current research outcomes and future prospects from experts across multiple disciplines. First, this study comprehensively reviews existing blue-health research evidence from a spatial design perspective and constructs a methodological framework for translating health-promoting evidence into actionable design knowledge. Through an analysis of global precedents and site-specific explorations in Rotterdam, the study develops practical knowledge for integrating the health benefits of blue spaces into design practice. Additionally, the study evaluates the effectiveness and feasibility of the newly developed design knowledge through design workshops. Finally, expert interviews are conducted to gather insights from researchers and practitioners about the current research outcomes. These discussions also explore the broader challenges associated with implementing the health benefits of natural environments in spatial practice and the potential for integrating a wider public health agenda into spatial interventions.

The findings indicate that design knowledge derived from research evidence holds the substantial potential to assist practitioners in incorporating the health-promoting effects of blue spaces into spatial practices. Conducting an overview and analysing existing studies prove highly beneficial in recognising the value of this evidence from a design perspective and in summarising four key design themes. These themes provide a crucial foundation for constructing a methodological framework that bridges evidence to practice. This framework not only offers support to practitioners in translating evidence but also effectively organises the various components of this study, enhancing the coherence.

Guided by the methodological framework, the study identifies and generates design knowledge comprising design principles, spatial patterns, and evaluation methods tailored to different design themes. For themes related to accessibility, visibility, and quantity, the study utilises worldwide precedent studies and gathers interdisciplinary tools to generate design knowledge. For themes associated with quality, the design knowledge is developed and refined based on collecting local evidence, utilising crowdsourced data, and factoring in the specific activity types and demographic groups in Rotterdam. This dual approach underscores the adaptability of the framework to diverse sources and scales of data, enhancing its relevance and applicability in varying contexts.

As demonstrated in the design workshop, the generated design knowledge has shown potential to assist practitioners with spatial design, providing designers with direct tools while maintaining flexibility in the design process. However, it is crucial to recognise that the current design knowledge is not definitive and requires continual refinement as new evidence and interdisciplinary tools become available. The feedback from expert interviews validates the current research outcomes and underscores the necessity for ongoing enhancements. Future research and practice should aim to more precisely quantify the relationship between the health-promoting effects of blue spaces and spatial interventions. Additionally, this study positions blue space as a type of urban public space, treating water quality not as a primary focus but as a foundational prerequisite for achieving the health benefits discussed. It underscores the importance of public health as a central objective in urban interventions and policy-making through interdisciplinary collaboration. Although the research highlights the diverse health benefits of blue space exposure, the contributions of environmental and public health scholars in maintaining clean and safe conditions are crucial for implementing these findings. Such collaborative efforts are essential for building ‘healthy cities’ and advancing sustainable development goals.

Appendices

APPENDIX A

Design Principles & Spatial Patterns for Healthy Blue Spaces

The first part of the appendix presents the design booklet, which aligns with the research findings discussed in Chapters 5 and 6 of the thesis. This booklet outlines design principles and spatial patterns for improving blue spaces across four design themes to fulfill their health benefits. Consequently, the booklet is organised by these four themes (i.e. quantity, accessibility, visibility, and quality), with each theme's principles and patterns further categorised based on the scale and spatial elements of the blue space. Furthermore, as detailed in the thesis, each design principle may encompass multiple specific spatial patterns. Accompanying each principle or pattern are descriptions of the application scale, location, related design concepts, evaluation methods, and application notes, all intended to support designers in practical implementation.

Design Principles & Spatial Patterns

for Healthy Blue Spaces

A-01

List of Icons

Design principles and spatial patterns for blue space quantity

Application Scales: Refers to the scales of blue spaces

Large Medium Small

Morphology: Distinguish the morphological feature of water bodies

Linear Planar

Origin: Indicate the sources of water bodies within blue spaces

Natural Artificial

Provision Difficulty: The degree of difficulty in practical application

Hard Medium Easy

Design principles and spatial patterns for blue space accessibility, visibility, and quality

Application Scales: Refers to the scales of spatial interventions or projects suitable for the spatial patterns

Regional/City Intermediate Individual

Locations: Identify the locations of spatial elements related to patterns

Internal Factors External Factors

Linked Concepts (Accessibility & Visibility): Design concepts linked to spatial patterns

Design Concepts of Accessibility

Walking Road Network Public Transportation Hydrophilicity

Design Concepts of Visibility

Passive Commuting Working Residential

Methods (Accessibility & Visibility): Analytical tools for evaluating the effectiveness of the pattern

M-A/V-1: M refers to methods, **A/V** refers to accessibility and visibility, **1** refers to method number.

M-A-1 → Statistical Index Approach M-A-2 → Spatial Interaction Approach
M-A-3 → Spatial Proximity Approach M-A-4 → 3D Landscape Analysis
M-A-5 → Spatial Configurational Approach
M-V-1 → Statistical Index Approach M-V-2 → Spatial Oriented Approach
M-V-3 → Object-based Approach M-V-4 → 3D Landscape Analysis
M-V-5 → Segmentation Analysis

Activity Type (Quality): Spatial patterns specific to activity types

Running Cycling

A-02

Contents of Principles and Patterns

A-03

Spatial Quantity

Spatial accessibility is critical for individual' s contact and usage of blue spaces, thus significantly influencing the health outcomes of blue spaces. Existing studies suggest that improving the spatial accessibility could be beneficial for fulfilling the health benefits of blue spaces, especially in urban contexts.

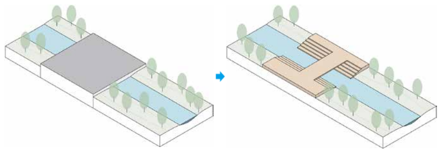
In this section, the design principles and spatial patterns for improving spatial accessibility of blue spaces will be domonstrated. Notably, the principles and patterns mainly emphasises the spatial accessibility from the objective perspective.

Futhermore, the design principles and spatial patterns might be presented together with the scales for applications, degree of difficulty in implementation, and the detailed design concepts from review of current studies.

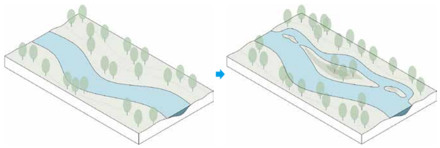
A-04

Blue Space Quantity

Design Principles:
Re-connecting/developing water systems
Application Note:
Considering integrating natural water bodies when implementing this
Spatial Patterns 1
Reconnecting historical water bodies

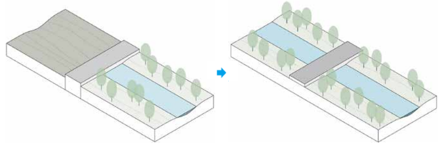


Spatial Patterns 2
Creating temporary blue spaces aligning to other demands

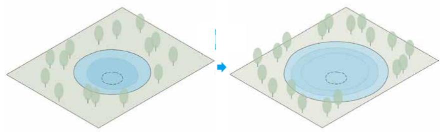


Blue Space Quantity

Design Principles:
Expanding existing water bodies
Application Note:
Considering the spatial requirement for the water bodies
Spatial Patterns 1
Revitalising existing water bodies



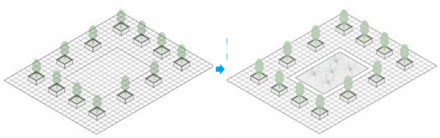
Spatial Patterns 2
Expanding current water bodies



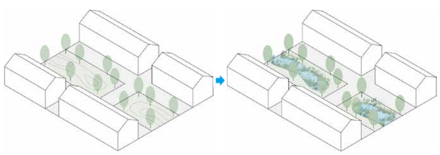
A-05

Blue Space Quantity

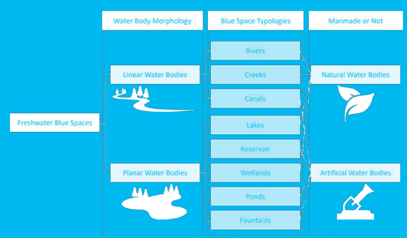
Design Principles:
Creating new freshwater blue spaces
Application Note:
Considering sources of the supplementing water, such as rainwater
Spatial Patterns 1
Adding freshwater blue spaces at existing open spaces



Spatial Patterns 2
Creating temporary blue spaces aligning to other demands



Types of Freshwater Blue Space

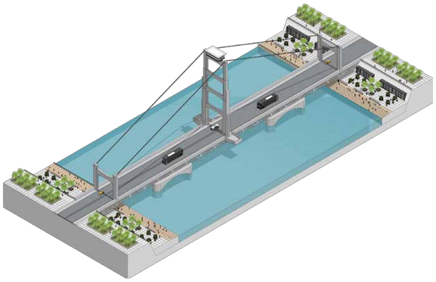


A-06

Rivers

Definition:

Water courses within a city/urban land including riparian areas/ stripes and water front areas, riverbank



Rhone riverbank, Lyon, FR
IN SITU Paysages & urbanisme

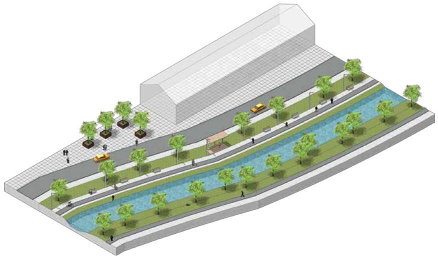
Douro river, Porto, PT
Self photoed

Spatial Scale	Morphology	Origin	Provision Difficulty
Large/Medium	Linear	Natural	Hard

Creeks

Definition:

Water courses within a city/urban land including riparian areas/ stripes and water front areas, riverbank



Mill River Park, Connecticut, USA
OLIN

Het park, Rotterdam, NL
Self photoed

Spatial Scale	Morphology	Origin	Provision Difficulty
Medium/Small	Linear	Natural	Medium

A-07

Canals

Definition:

Water courses within a city/urban land including riparian areas/ stripes and water front areas, riverbank

Cheonggyecheon River, Seoul, KR
Mikyoung Kim Design

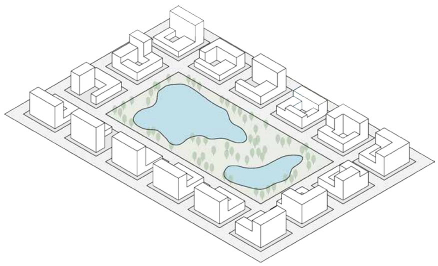
Urban canal, Amsterdam, NL
Self photoed

Spatial Scale	Morphology	Origin	Provision Difficulty
Medium/Small	Linear	Artificial	Medium

Lakes

Definition:

Water courses within a city/urban land including riparian areas/ stripes and water front areas, riverbank



Central Park, New York, USA
Frederick Law Olmsted

Longzhou lake, Xiamen, CN
Self photoed

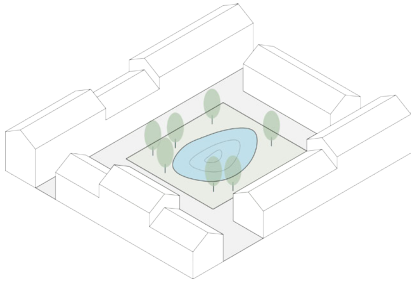
Spatial Scale	Morphology	Origin	Provision Difficulty
Large/Medium	Planar	Natural	Hard

A-08

Ponds

Definition:

Water courses within a city/urban land including riparian areas/ stripes and water front areas, riverbank



Bjerkedalen Park, Oslo, NO
IN SITU Paysages & urbanisme

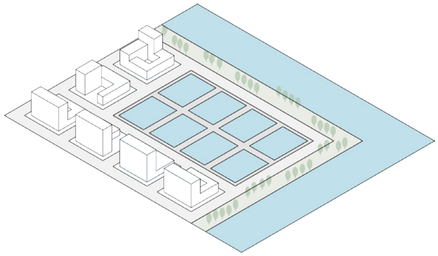
Tuin Schoonoord, Rotterdam, NL
Self photoed

Spatial Scale	Morphology	Origin	Provision Difficulty
Small	Planar	Natural	Easy

Reservoir

Definition:

Water courses within a city/urban land including riparian areas/ stripes and water front areas, riverbank



Banbury Reservoir, London, UK
www.webbaviation.co.uk

West Warwick Reservoir, London, UK
Wikipedia

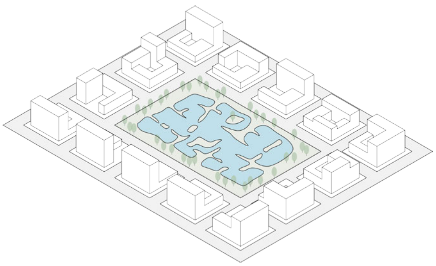
Spatial Scale	Morphology	Origin	Provision Difficulty
Large/Medium	Planar	Artificial	Hard

A-09

Wetlands

Definition:

Water courses within a city/urban land including riparian areas/ stripes and water front areas, riverbank



Qiaoyuan wetland park, Tianjin, CN
Turenscape

University lake, Wageningen, NL
Self photoed

Spatial Scale	Morphology	Origin	Provision Difficulty
Large/Medium	Planar	Natural	Hard

Fountains

Definition:

Water courses within a city/urban land including riparian areas/ stripes and water front areas, riverbank

Promenade du Paillon, Nice, FR
Pend Paysages

Lustgarten, Berlin, DE
Self photoed

Spatial Scale	Morphology	Origin	Provision Difficulty
Small	Planar	Artificial	Easy

A-10

Spatial Accessibility

Spatial accessibility is critical for individual' s contact and usage of blue spaces, thus significantly influencing the health outcomes of blue spaces. Existing studies suggest that improving the spatial accessibility could be beneficial for fulfilling the health benefits of blue spaces, especially in urban contexts.

In this section, the design principles and spatial patterns for improving spatial accessibility of blue spaces will be domonstrated. Notably, the principles and patterns mainly emphasises the spatial accessibility from the objective perspective.

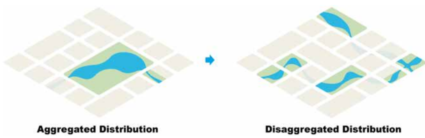
Futhermore, the design principles and spatial patterns might be presented together with the scales for applications, degree of difficulty in implementation, and the detailed design concepts from review of current studies.

A-11

Blue Space Distribution

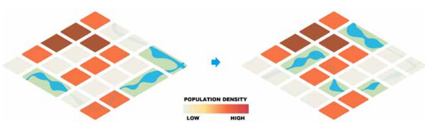
Design Principles:
Improving distributions of freshwater blue spaces in urban contexts

Spatial Patterns 1
Placing the freshwater blue spaces in a disaggregated spatial distribution



Application Scale	Locations	Linked Concepts	Methods
Regional/City	Internal Factors		M-A-1/2

Spatial Patterns 2
Placing the freshwater blue spaces adjacent to areas with high population density

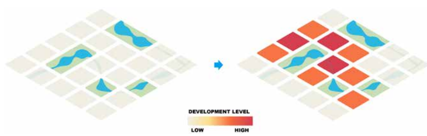


Application Scale	Locations	Linked Concepts	Methods
Regional/City	Internal Factors		M-A-1/2

Development Area Selection

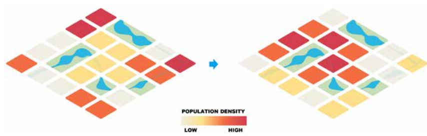
Design Principles:
Urban areas for the future developments with great accessibility of blue spaces

Spatial Patterns 1
Selecting the Areas with great blue accessibility for future developments



Application Scale	Locations	Linked Concepts	Methods
Regional/City	Internal Factors		M-A-1/2

Spatial Patterns 2
Placing urban areas with high population density adjacent to the blue spaces



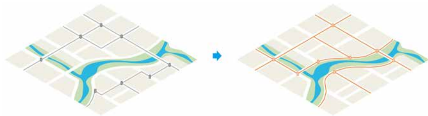
Application Scale	Locations	Linked Concepts	Methods
Regional/City	Internal Factors		M-A-1/2

A-12

Public Transportation System

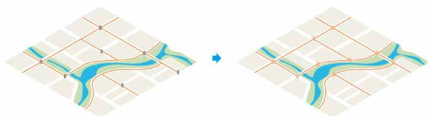
Design Principles:
Well-plan public transportation system to improve accessibility of blue spaces

Spatial Patterns 1
Arranging the public transport lines alongside the main urban water bodies



Application Scale	Locations	Linked Concepts	Methods
Regional/City	External Factors		M-A-3/5

Spatial Patterns 2
Planning multiple public transportation stations (stops) near the urban blue spaces

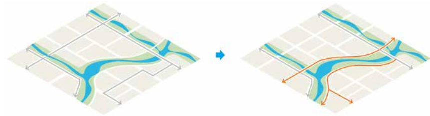


Application Scale	Locations	Linked Concepts	Methods
Regional/City	External Factors		M-A-3/5

Main Road Structure

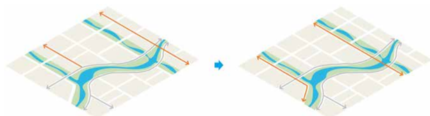
Design Principles:
Enhancement of the main road structure to improving accessibility of blue spaces

Spatial Patterns 1
Using the waterfront roads as structural elements to organize the road network



Application Scale	Locations	Linked Concepts	Methods
Regional/City	External Factors		M-A-3/5

Spatial Patterns 2
Arranging main roads/streets adjacent to the large water bodies in urban environments



Application Scale	Locations	Linked Concepts	Methods
Regional/City	External Factors		M-A-3/5

A-13

Internal Road Network

Design Principles:
Adjustment the road network within blue spaces to contact water bodies

Spatial Patterns 1
Improving the overall connectivity of roads within the blue spaces

Application Scale	Locations	Linked Concepts	Methods
Intermediate	Internal Factors		M-A-3/5

Spatial Patterns 2
Arranging more roads within blue spaces located next to/above the water bodies

Application Scale	Locations	Linked Concepts	Methods
Intermediate	Internal Factors		M-A-3/5

A-14

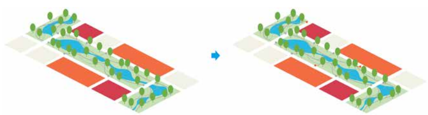
Blue Space Entrances

Design Principles:
Improvement of the spatial arrangement of blue space entrances

Spatial Patterns 1
Placing the blue space entrances in conjuction with adjacent road/ street intersections

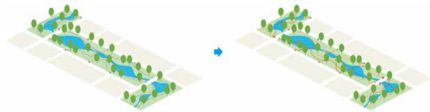
Application Scale	Locations	Linked Concepts	Methods
Regional/City	Internal Factors		M-A-3

Spatial Patterns 2
Arranging the blue space entrances adjacent to high-populated areas



Application Scale	Locations	Linked Concepts	Methods
Regional/City	Internal Factors		M-A-2/3

Spatial Patterns 3
Increasing the quantity of blue space entrances

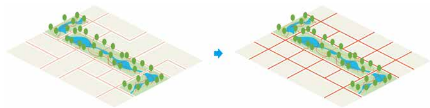


Application Scale	Locations	Linked Concepts	Methods
Intermediate	External Factors		M-A-3

Local Road Network

Design Principles:
Adjustment the adjacent road network of blue spaces for well accessible

Spatial Patterns 1
Imcreasing the overall density of the roads/streets within adjacent urban areas of blue spaces

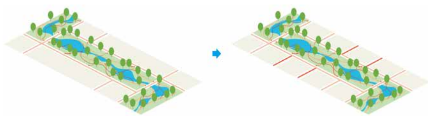


Application Scale	Locations	Linked Concepts	Methods
Intermediate	External Factors		M-A-3/5

A-15

Local Road Network

Spatial Patterns 2
Arranging more direct connections (roads/streets) to reach the blue spaces



Application Scale	Locations	Linked Concepts	Methods
Regional/City	External Factors		M-A-3/5

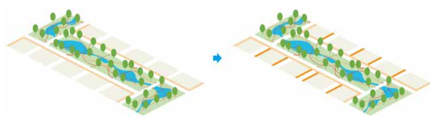
Spatial Patterns 3
Providing extra informal connections between blue spaces and adjacent urban areas

Application Scale	Locations	Linked Concepts	Methods
Regional/City	External Factors		M-A-3/5

Cycling/Walking Network

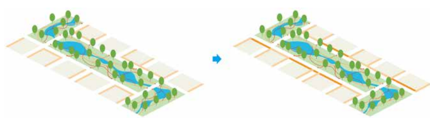
Design Principles:
Well-planned cycling/walking route network could make visit blue spaces much easier

Spatial Patterns 1
Increasing existing cycling/walking route network adjacent to blue spaces



Application Scale	Locations	Linked Concepts	Methods
Intermediate	External Factors		M-A-3

Spatial Patterns 2
Extending existing cycling/walking route network adjacent to blue spaces for greater network connectivity

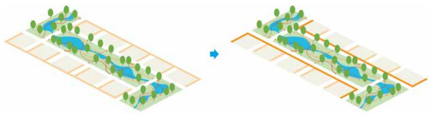


Application Scale	Locations	Linked Concepts	Methods
Intermediate	External Factors		M-A-3

A-16

TOC

Spatial Patterns 3
Placing the cycling/walking route network adjacent to blue spaces

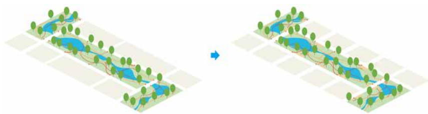


Application Scale	Locations	Linked Concepts	Methods
Regional/City	External Factors		M-A-3

Parking Area Planning

Design Principles:
Improvement of the spatial planning of blue space surrounding parking areas

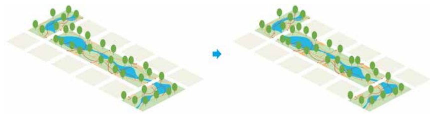
Spatial Patterns 1
Arranging the parking areas of blue spaces located adjacent to the entrances



Application Scale	Locations	Linked Concepts	Methods
Regional/City	Internal Factors		M-A-1

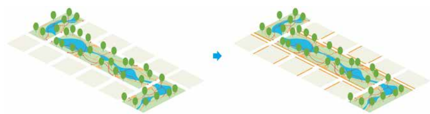
Parking Area Planning

Spatial Patterns 2
Provding support for diverse parking demands (e.g. private car, bus, bicycle, etc)



Application Scale	Locations	Linked Concepts	Methods
Intermediate	Internal Factors		M-A-1

Spatial Patterns 3
Setting up temporary parking areas based to the surrounding traffic flow



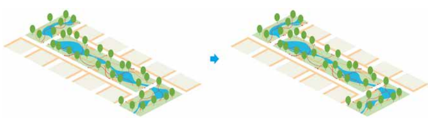
Application Scale	Locations	Linked Concepts	Methods
Intermediate	External Factors		M-A-1

A-17

Public Transport Stations/Stops Planning

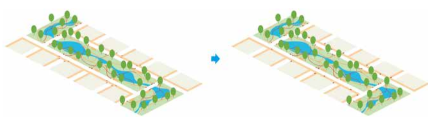
Design Principles:
Improvement of the spatial arrangement of public transport stations/stops near blue spaces

Spatial Patterns 1
Arranging the public transport stations/stops adjacent to the entrances of blue spaces



Application Scale	Locations	Linked Concepts	Methods
Regional/City	Internal Factors		M-A-3

Spatial Patterns 2
Planning spatial distribution of the stations/stops near the blue spaces equally



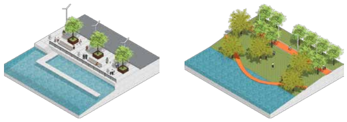
Application Scale	Locations	Linked Concepts	Methods
Regional/City	External Factors		M-A-3

A-18

Internal Road Design

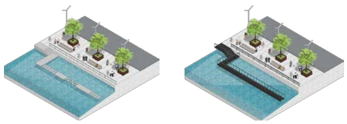
Design Principles:
Improvement of the detailed spatial design of the internal blue space roads/streets to contact water directly

Spatial Patterns 1
Constructing the roads/streets directly on the water bodies
Application Note:
Considering the depth of the water on both sides of the road



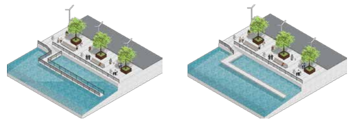
Application Scale	Locations	Linked Concepts	Methods
Individual	Internal Factors		M-A-4

Spatial Patterns 2
Making the surface of the roads more transparent to water bodies
Application Note:
Considering the size of the gaps to suit the demands of elderly and children



Application Scale	Locations	Linked Concepts	Methods
Individual	Internal Factors		M-A-4

Spatial Patterns 3
Making the railing of the roads more transparent to water bodies
Application Note
Considering the depth of the water on both sides of the road when using the lower handrails

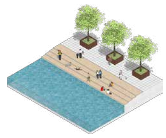


Application Scale	Locations	Linked Concepts	Methods
Individual	Internal Factors		M-A-4

Contacting Facilities

Design Principles:
Provision of the contacting facilities of water bodies in blue spaces

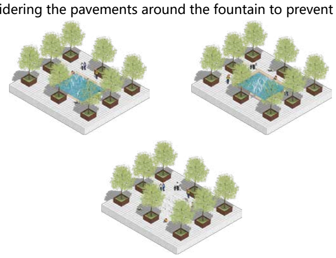
Spatial Patterns 1
Using the steps to contacting water bodies
Application Note
Noticing the overall slope of steps for the vulnerable groups and the width of each step to meet multiple demands
Considering the depth of water adjacent to the steps



Application Scale	Locations	Linked Concepts	Methods
Individual	Internal Factors		M-A-4

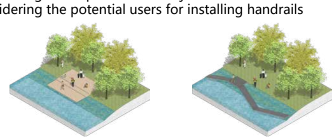
A-19

Spatial Patterns 2
Utilising fountains or recreational installations to contact water
Application Note
Considering the pavements around the fountain to prevent slipping



Application Scale	Locations	Linked Concepts	Methods
Individual	Internal Factors		M-A-4

Spatial Patterns 2
Providing on water platforms or decks to contact water
Application Note:
Considering the depth of water adjacent to the facilities
Considering the potential users for installing handrails

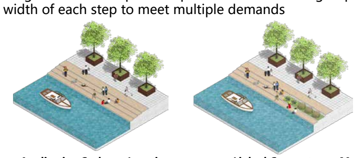


Application Scale	Locations	Linked Concepts	Methods
Individual	Internal Factors		M-A-4

Water Edges

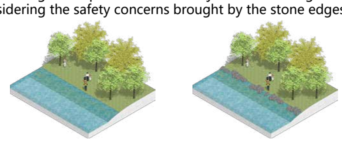
Design Principles:
Improvement of the detailed spatial design of the water edges to contact water directly

Spatial Patterns 1
Examples of the redesign of hard edges to contact water
Application Note
Noticing the overall slope of steps for the vulnerable groups and the width of each step to meet multiple demands



Application Scale	Locations	Linked Concepts	Methods
Individual	Internal Factors		M-A-4

Spatial Patterns 2
Examples of the redesign of soft edges to contact water
Application Note
Considering the depth of the water adjacent to the edges
Considering the safety concerns brought by the stone edges



Application Scale	Locations	Linked Concepts	Methods
Individual	Internal Factors		M-A-4

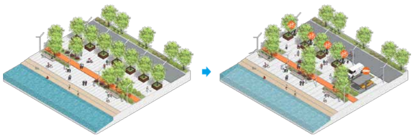
A-20

TOC

Parking Facilities

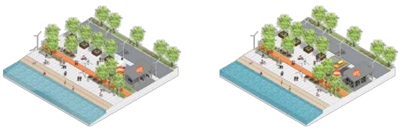
Design Principles:
Provision of the diverse and integrated parking facilities

Spatial Patterns 1
Providing diverse parking facilities (i.e. bicycles, private cars, etc.)
Application Note
Considering parking facilities do not interfere with the walking/ cycling routes



Application Scale	Locations	Linked Concepts	Methods
Individual	Internal Factors		M-A-4

Spatial Patterns 2
Providing integated facilities meeting diverse parking demands
Application Note
Noticing the complexity caused by the combination of diverse facilities
Considering the spatial requirement in the compact environments



Application Scale	Locations	Linked Concepts	Methods
Individual	Internal Factors		M-A-4

Crossing Facilities

Design Principles:
Provision of the crossing facilties linking blue spaces with surroundings

Spatial Patterns 1
Providing the pedestrian crossings on roads
Application Note
Combining the crossings with the entrance of the blue spaces

Application Scale	Locations	Linked Concepts	Methods
Individual	Internal Factors		M-A-4

Spatial Patterns 2
Utilising the underpass as the crossing facilities
Application Note
Considering the space required for constructing the underpass
Providing the barrier-free facilities

Application Scale	Locations	Linked Concepts	Methods
Individual	Internal Factors		M-A-4

A-21

Spatial Patterns 3
Utilising overpass to link surrounding urban areas with blue spaces
Application Note
Considering the space required for constructing the overpass
Providing the barrier-free facilities

Application Scale	Locations	Linked Concepts	Methods
Individual	Internal Factors		M-A-4

Spatial Patterns 4
Utilising overpass to direct link surrounding buildings with blue spaces
Application Note
Considering the synergy with the surrounding buildings (functions, spatial requirements)
Providing the barrier-free facilities

Application Scale	Locations	Linked Concepts	Methods
Individual	Internal Factors		M-A-4

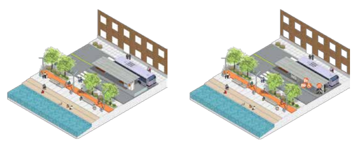
Transportation Stations

Design Principles:
Improvement of the detailed design of the bus stations

Spatial Patterns 1
Connecting the bus stations with the entrances of blue spaces
Application Note
Providing the barrier-free facilities

Application Scale	Locations	Linked Concepts	Methods
Individual	External Factors		M-A-4

Spatial Patterns 2
Integrating multiple services in bus station
Application Note
Considering the space required for the multi-services



Application Scale	Locations	Linked Concepts	Methods
Individual	External Factors		M-A-4

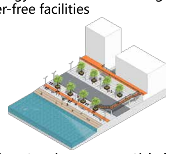
A-22

Walking/cycling Route Design

Design Principle
Improvement of the detailed design of walking/cycling routes
Spatial Pattern 1
Linking cycling routes with the entrances and parking facilities
Application Note
Providing the sufficient space
Avoiding interfere with the other routes

Application Scale	Locations	Linked Concepts	Methods
Individual	Internal Factors		M-A-4

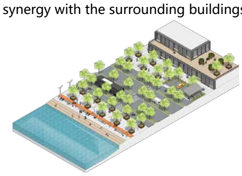
Spatial Pattern 2
Integrating the walking routes with the surrounding buildings
Application Note
Considering the synergy with the surrounding buildings
Providing the barrier-free facilities



Application Scale	Locations	Linked Concepts	Methods
Individual	Internal Factors		M-A-4

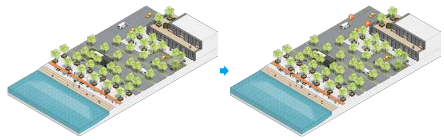
Parking Facilities

Design Principle
Sustainable usage of the surrounding outside parking areas
Spatial Pattern 1
Sharing the parking areas with the surroundding facilities
Application Note
Noticing the synergy with the surrounding buildings



Application Scale	Locations	Linked Concepts	Methods
Individual	External Factors		M-A-4

Spatial Pattern 2
Utilising roads/streets as parking areas during off-peak hours
Application Note
Considering the potential issues related to post maintenance



Application Scale	Locations	Linked Concepts	Methods
Individual	External Factors		M-A-4

A-23

Spatial Visibility

Spatial visibility is critical for individual' s to interact with blue spaces, thus significantly influencing the health outcomes of blue spaces. Existing studies suggest that improving the spatial visibility could be beneficial for fulfilling the health benefits of blue spaces, especially in urban contexts.

In this section, the design principles and spatial patterns for improving spatial visibility of blue spaces will be demonstrated. Similar to the spatail accessibility and quantity, the principles and patterns also primaryly emphasises the spatial accessibility from the objective perspective.

Futhermore, the design principles and spatial patterns might be presented together with the scales for applications, the type of spatial elements, and the detailed design concepts from review of current studies.

A-24

Blue Space Distribution

Design Principles:
Improving spatial distributions of blue spaces for better visibility

Spatial Patterns 1
Emphasing the spatial distributions of the blue spaces with large water bodies

Application Scale	Locations	Linked Concepts	Methods
Regional/City	External Factors		M-V-1/2

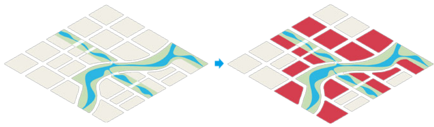
Spatial Patterns 2
Arranging the blue spaces in a disaggragted spatial distribution for enhancing the visibility potential

Application Scale	Locations	Linked Concepts	Methods
Regional/City	Internal Factors		M-V-1/2

Development Area Selection

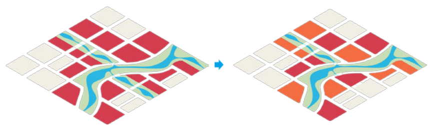
Design Principles:
Urban areas for the future developments with great visibility

Spatial Patterns 1
Selecting the areas located adjacent to the blue spaces for future developments



Application Scale	Locations	Linked Concepts	Methods
Regional/City	External Factors		M-V-1/2

Spatial Patterns 2
Embracing the diverse land use types in surrounding areas of blue spaces to provide blue visibility to more people



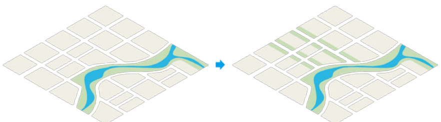
Application Scale	Locations	Linked Concepts	Methods
Regional/City	External Factors		M-V-1/2

A-25

Structure of Viewing Corridors

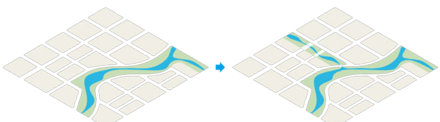
Design Principles:
Using viewing corridors to link blue spaces and surrouding areas

Spatial Patterns 1
Utilising the main roads/streets as the viewing corridors for urban blue spaces



Application Scale	Locations	Linked Concepts	Methods
Regional/City	External Factors		M-V-1/2

Spatial Patterns 2
Emphasising some linear natural elements (e.g. canals, rivers, green spaces) as the urban viewing corridors



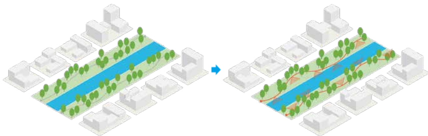
Application Scale	Locations	Linked Concepts	Methods
Regional/City	Internal Factors		M-V-1/2

A-26

Road Network

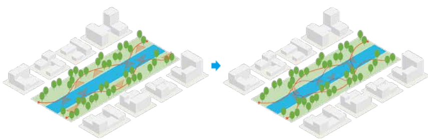
Design Principles:
Improvement of the spatial arrangement of road network within blue spaces for better blue visibility

Spatial Patterns 1
Placing the main roads/streets within blue spaces located adjacent to the water bodies



Application Scale	Locations	Linked Concepts	Methods
Intermediate	Internal Factors		M-V-3/5

Spatial Patterns 2
Arranging the sub-roads within blue spaces located above or in water bodies

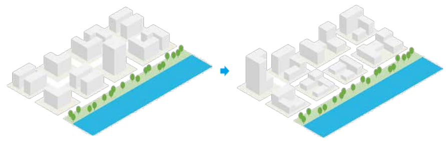


Application Scale	Locations	Linked Concepts	Methods
Intermediate	Internal Factors		M-V-3/5

Building Layout

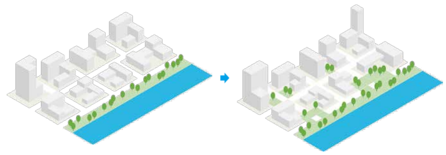
Design Principles:
Adjustment of building/block layout of blue space' s surrounding areas for better blue visibility

Spatial Patterns 1
Optimsing the height of the surrounding building/blocks to provide better blue view for remote building/blocks



Application Scale	Locations	Linked Concepts	Methods
Intermediate	Internal Factors		M-V-2/3

Spatial Patterns 2
Extending the blue spaces into surrounding areas or connecting with buildings for better blue view



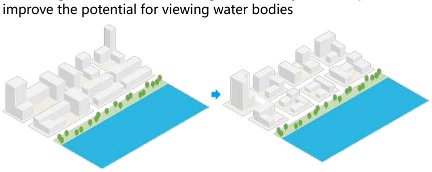
Application Scale	Locations	Linked Concepts	Methods
Regional/City	Internal Factors		M-V-2/3

A-27

Road Network

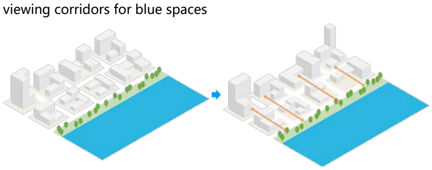
Design Principles:
Improvement of the surrounding road network of blue spaces to enhancing blue visibility

Spatial Patterns 1
Increasing the overall surrounding road denisty of blue spaces to improve the potential for viewing water bodies



Application Scale	Locations	Linked Concepts	Methods
Intermediate	External Factors		M-V-2/3

Spatial Patterns 2
Developing some informal connections as the supplementary viewing corridors for blue spaces

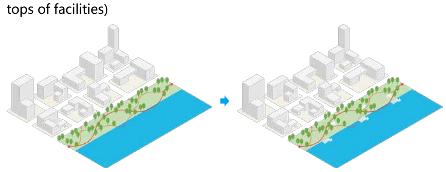


Application Scale	Locations	Linked Concepts	Methods
Intermediate	External Factors		M-V-2/3

Landscape Element Arrangements

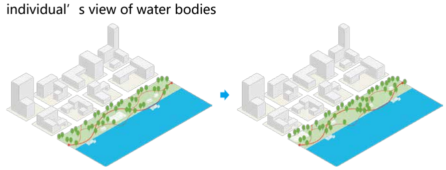
Design Principles:
Utilising the landscape elements and optimising their spatial arrangements to improve blue visibility

Spatial Patterns 1
Providing more landscape elements (e.g. viewing platforms, rooftops of facilities)



Application Scale	Locations	Linked Concepts	Methods
Intermediate	Internal Factors		M-V-3/4/5

Spatial Patterns 2
Preventing landscape elements of blue spaces from obstructing individual' s view of water bodies

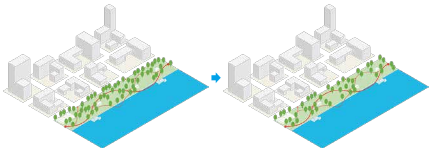


Application Scale	Locations	Linked Concepts	Methods
Regional/City	Internal Factors		M-V-3/4/5

A-28

TOC

Spatial Patterns 3
Considering the combinations of vegetations and landscape elements to expand the blue visibility

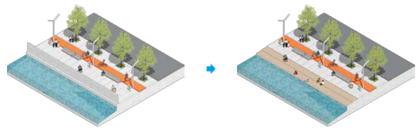


Application Scale	Locations	Linked Concepts	Methods
Intermediate	Internal Factors		M-V-3/4/5

Water Edges

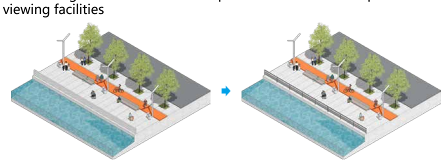
Design Principles:
Improvement of the elements of water edges

Spatial Patterns 1
Removing the obstacles in water edges to provide greater blue visibility
Application Note
Maintaining the quality of the water bodies before open up
Considering the safety concerns for the vulnerable groups



Application Scale	Locations	Linked Concepts	Methods
Individual	Internal Factors		M-V-4/5

Spatial Patterns 2
Making the elements of water edge (e.g. railings) more transparent
Application Note
Considering the investment of implementation and incorporate with viewing facilities



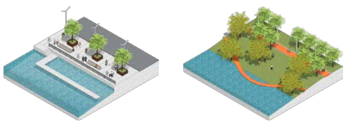
Application Scale	Locations	Linked Concepts	Methods
Individual	Internal Factors		M-V-4/5

A-29

Internal Road Design

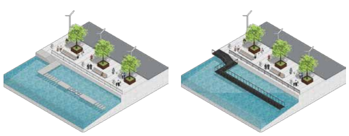
Design Principles
Improvement of the detailed design of the internal blue space roads

Spatial Pattern 1
Constructing the roads/streets directly on the water bodies
Application Note
Considering the depth of the water on both sides of the road



Application Scale	Locations	Linked Concepts	Methods
Individual	Internal Factors		M-V-4

Spatial Pattern 2
Making the surface of the roads more transparent to water bodies
Application Note
Considering the size of the gaps to suit the demands of elderly and children

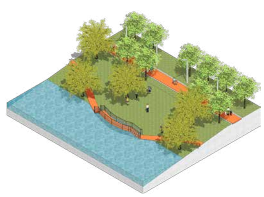


Application Scale	Locations	Linked Concepts	Methods
Individual	Internal Factors		M-V-4

Spatial Pattern 3
Making the railing of the roads more transparent to water bodies
Application Note
Considering the depth of the water on both sides of the road when using the lower handrails

Application Scale	Locations	Linked Concepts	Methods
Individual	Internal Factors		M-V-4

Spatial Pattern 4
Making the blue space road higher to obtain the greater water view
Application Note
Considering the safety concerns for the vulnerable groups
Providing the barrier-free facilities if possible



Application Scale	Locations	Linked Concepts	Methods
Individual	Internal Factors		M-V-4/5

A-30

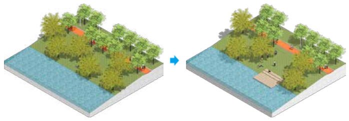
TOC

Vegetation Design

Design Principle
Improvement of detailed vegetation design of internal blue spaces

Spatial Pattern 1
Optimising the spatial arrangement of vegetations to avoid blocking blue view

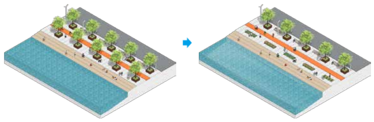
Application Note
Prefering to combine with open spaces and other facilities



Application Scale	Locations	Linked Concepts	Methods
Individual	Internal Factors		M-V-4/5

Spatial Pattern 2
Placing the shrubs or vegetations with limit canopy located next to the water body to expand blue visibility

Application Note
Considering temporary shading facilities



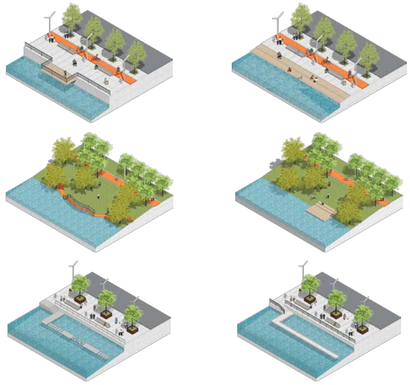
Application Scale	Locations	Linked Concepts	Methods
Individual	Internal Factors		M-V-4/5

Viewing Facilities

Design Principle
Provision of viewing facilities， especially for the symbolic water bodies

Spatial Pattern 1
Providing various type of viewing facilities within blue spaces for better blue visibility

Application Note
Considering the concerns of safety for the vulnerable groups
Better to implement several patterns together

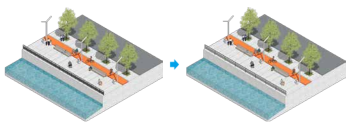


Application Scale	Locations	Linked Concepts	Methods
Individual	Internal Factors		M-V-4

A-31

Spatial Patterns 2
Making the viewing facilities more transparent
Or Providing external viewing facilities for the water bodies

Application Note
Considering the investment of implementation and incorporating with viewing facilities if possible



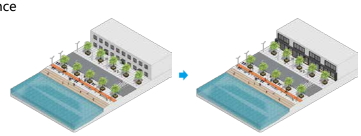
Application Scale	Locations	Linked Concepts	Methods
Individual	Internal Factors		M-V-4

Building Design

Design Principle
Improvement of the detailed spatial design of the surrounding buildings to expand water visibility

Spatial Pattern 1
Expanding size of the windows or doors of building

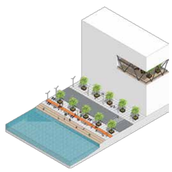
Application Note
Analyzing the potential of expanding for original buildings in advance



Application Scale	Locations	Linked Concepts	Methods
Individual	External Factors		M-V-3/4

Spatial Patterns 2
Providing viewing platform within the high rise buildings

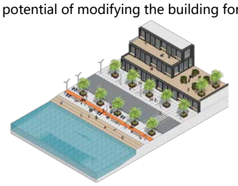
Application Note
Analyzing the potential of setting viewing platform of original buidings in advance (i.e. structure potential)
Considering the management issues related to opening to public



Application Scale	Locations	Linked Concepts	Methods
Individual	External Factors		M-V-3/4

Spatial Patterns 3
Optimising the building form to provide greater blue view

Application Note
Analyzing the potential of modifying the building form in advance



Application Scale	Locations	Linked Concepts	Methods
Individual	External Factors		M-V-3/4

A-32

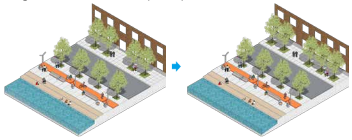
TOC

Vegetation Design

Design Principle
Improvement of the detailed spatial design of the vegetations

Spatial Pattern 1
Avoiding placing the the vegetations directly in front of the windows

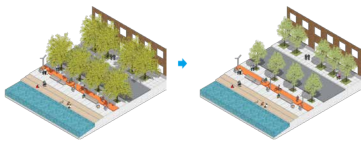
Application Note
Prefering to combine with open spaces and other facilities



Application Scale	Locations	Linked Concepts	Methods
Individual	External Factors		M-V-3/4

Spatial Patterns 2
Limiting the size of the canopy of vegetations to expand blue view

Application Note
Considering temporary shading facilities



Application Scale	Locations	Linked Concepts	Methods
Individual	External Factors		M-V-3/4

A-33

Spatial Quality

Spatial quality is critical for individual's contact and usage of blue spaces, thus significantly influencing the health outcomes of blue spaces. Existing studies suggest that diverse factors related to the spatial quality of blue space could be critical for fulfilling the health benefits of blue spaces, especially in urban contexts.

In this section, the design principles and spatial patterns for improving the spatial quality of blue spaces will be demonstrated. Unlike quantity, visibility, and accessibility, spatial quality is intimately linked to public perception and experience, making it highly sensitive to contextual factors. Consequently, the development of design principles and spatial patterns pertaining to the spatial quality of blue spaces is grounded in the analysis of site data from Rotterdam, the Netherlands.

Specifically, utilising crowdsourced data and a machine learning approach, this study first analyses the relationships between the blue space spatial quality and the recreational running/cycling amounts at the street level in Rotterdam, the Netherlands. Next, the analysis findings will be further translated into design principles and spatial patterns to develop excercise supportive and health-promoting blue spaces. Therefore, the design principles and spatial patterns presented below are based solely on analysis results, supporting the creation of blue spaces conducive to recreational running and cycling.

A-34

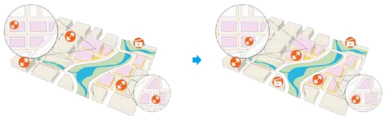
Land Use Planning

Design Principle
Improvment of the road network and land use pattern to attract more people to running or cycling in blue spaces

Spatial Pattern 1
Constructing the roads/streets directly on the water bodies

Application Scale Regional/City
Locations External Factors
Activity Type

Spatial Pattern 2
Placing the cultural and sport facilities located near blue spaces to attract running

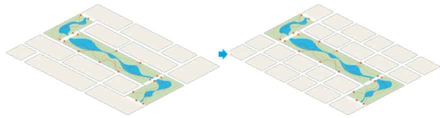


Application Scale Regional/City
Locations External Factors
Activity Type

Road Network

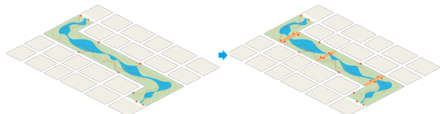
Design Principle
Adjustment of the surrounding road network of blue spaces to improve the connectivity for attracting running and cycling

Spatial Pattern 1
Improving overall connectivity of road network



Application Scale Intermediate
Locations Internal Factors
Activity Type

Spatial Pattern 2
Emphasising the improvement on choice rather than integration



Application Scale Intermediate
Locations Internal Factors
Activity Type

A-35

Traffic Facilities

Design Principle
Limiting the interference of public traffic facilities to individual' s environmental perception during running/cycling

Spatial Pattern 1
Keeping distance among public transport facilities and blue spaces

Application Scale Regional/City
Locations External Factors
Activity Type

Spatial Pattern 2
Maintainning sufficent distance between running/cycling routes with public traffic facilities

Application Scale Regional/City
Locations External Factors
Activity Type

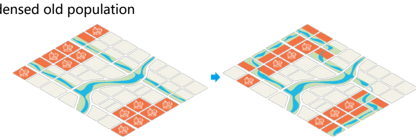
Spatial Distribution

Design Principle
The spatial distributions of blue spaces should align with the demands of the population groups

Spatial Pattern 1
Blue spaces in city centre designed for all age running, and blue spaces in urban fringes mainly consider the elderly running

Application Scale Regional/City
Locations External Factors
Activity Type

Spatial Pattern 2
Providing nearby blue spaces in neighbourhoods with highly densed old population



Application Scale Regional/City
Locations External Factors
Activity Type

A-36

Running/Cycling Route Planning

Design Principle
Planning running/cycling routes aligning with the blue space types

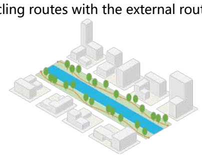
Spatial Pattern 1
Organising cycling/running routes around emblematic large-scale blue spaces
Application Note
Distinguishing two routes clearly to avoid interfering with each other

Application Scale: Intermediate | Locations: Internal Factors | Activity Type

Spatial Pattern 2
Coordinating running routes in conjunction with other recreational purposes in blue spaces
Application Note
Considering the spatial requirements of other recreational facilities

Application Scale: Intermediate | Locations: Internal Factors | Activity Type

Spatial Pattern 3
Designing cycling routes in harmony with linear blue spaces
Application Note
Connecting the cycling routes with the external routes

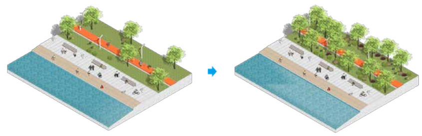


Application Scale: Intermediate | Locations: Internal Factors | Activity Type

Vegetation Design

Design Principle
Increasing greenery in blue spaces to improve the environmental perception and experience of multi-age groups running or cycling

Spatial Pattern 1
Introducing more eye-level vegetation or greenery in blue spaces
Application Note
Considering the tradeoff of visual openness



Application Scale: Individual | Locations: Internal Factors | Activity Type

A-37

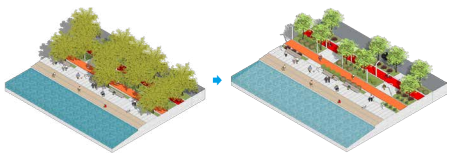
Spatial Pattern 2 (Elderly+Safety)
Increasing vegetations with regular configuration to reduce unsafety perception of the elderly
Application Note
Limiting the overall quantity of vegetation types

Application Scale: Intermediate | Locations: Internal Factors | Activity Type

Spatial Pattern 3 (Young+Complexity)
Increasing vegetations and spatial complexity with multi-layer configurations
Application Note
Maintaining the visibility of water bodies

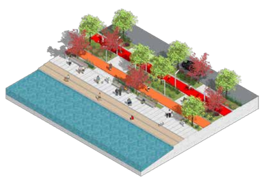
Application Scale: Intermediate | Locations: Internal Factors | Activity Type

Spatial Pattern 4 (Openness)
Utilising shrubs or limiting canopy size to maintain openness
Application Note
Considering the tradeoff of cooling effects provided by the canopy



Application Scale: Individual | Locations: Internal Factors | Activity Type

Spatial Pattern 5 (Young+Complexity)
Including various vegetation types to improve visual complextiy
Application Note
Considering the over-complicated vegetation



Application Scale: Individual | Locations: Internal Factors | Activity Type

A-38

Building Elements

Design Principle
Reducing the building elements in view during running or cycling

Spatial Pattern 1
Utilising vegetations to reduce building elements in view
Application Note
Choosing the appropriate species of trees based on local contexts

Application Scale	Locations	Activity Type
Intermediate	Internal Factors	

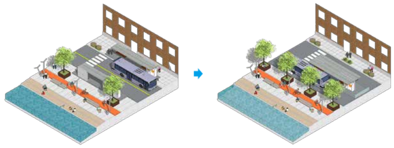
Spatial Pattern 2
Utilising vertical greenery to reduce building elements in view
Application Note
Considering the financial investment of the vertical greenery
Considering the implementation potential of the building surfaces

Application Scale	Locations	Activity Type
Intermediate	External Factors	

Traffic Elements

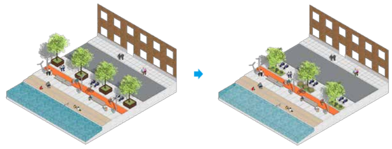
Design Principle
Reducing the traffic elements in view during running or cycling

Spatial Pattern 1
Optimising the spatial layout of traffic elements to reduce impact
Application Note
Considering the width of the streets for realising it



Application Scale	Locations	Activity Type
Individual	External Factors	

Spatial Pattern 2
Utilising the vegetations to reduce the traffic elements in view
Application Note
Considering spatial requirements to avoid interference



Application Scale	Locations	Activity Type
Individual	Internal Factors	

A-39

Public Facilities

Design Principle
Incorporating the temporary public facilities

Spatial Pattern 1
Increasing the service support by arranging temporary facilities
Application Note
Considering the potential post management issues

Application Scale	Locations	Activity Type
Intermediate	Internal Factors	

Spatial Pattern 2
Integrating the service support with others elements (e.g. bus stop)
Application Note
Considering the spatial requirements for the public facilities

Application Scale	Locations	Activity Type
Intermediate	External Factors	

A-40

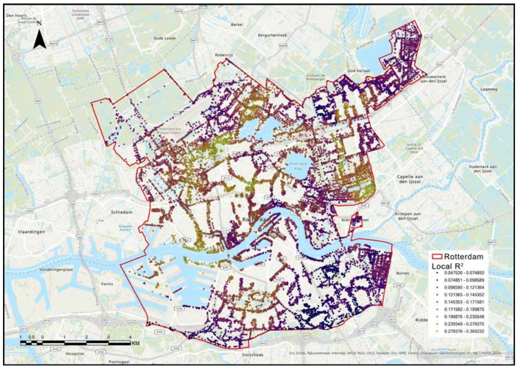
TOC

APPENDIX B

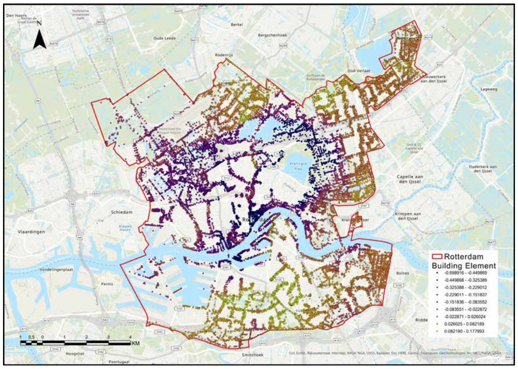
Full Results of GWR Analysis

GWR Analysis Results of 18-34 Group

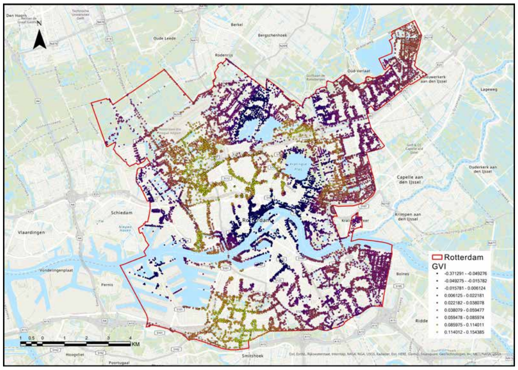
LOCAL R^2



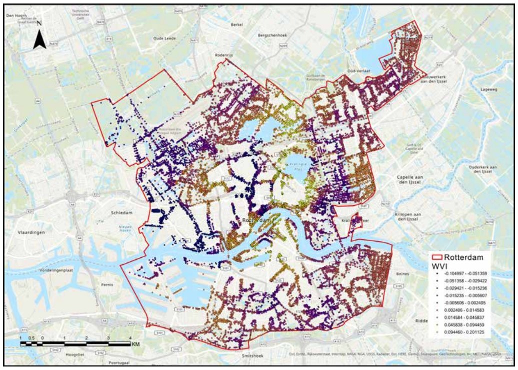
BUILDING ELEMENT



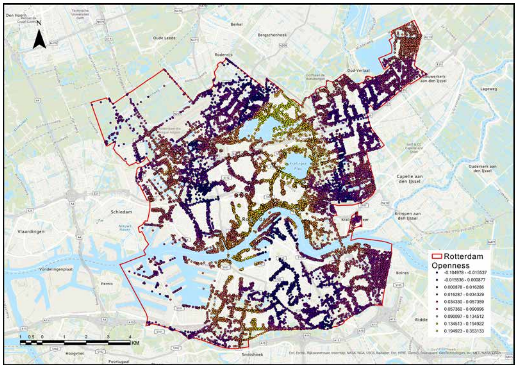
GREEN VIEW INDEX (GVI)



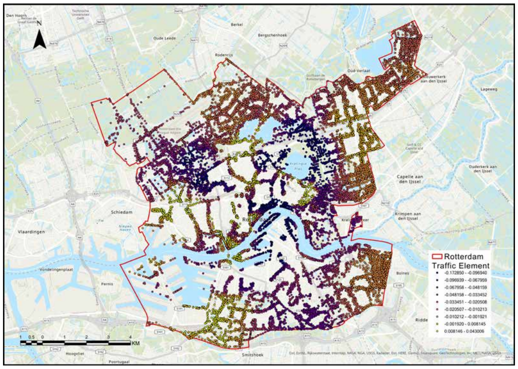
WATER VIEW INDEX (WVI)



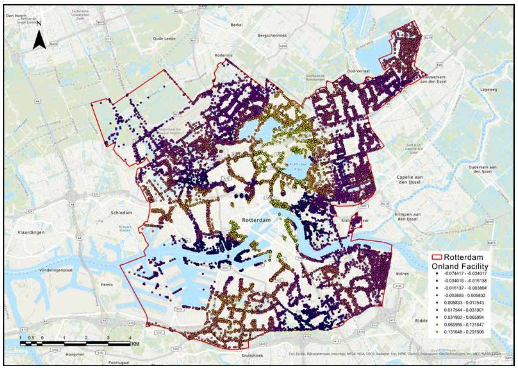
OPENNESS



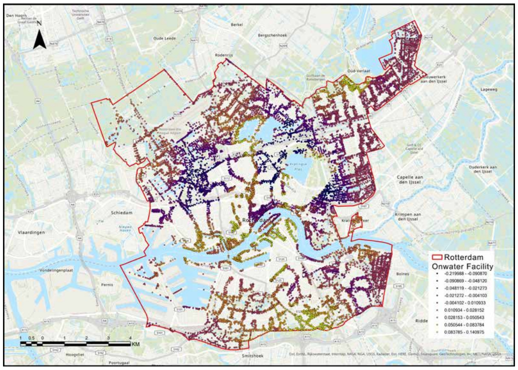
TRAFFIC ELEMENT



ON-LAND FACILITY

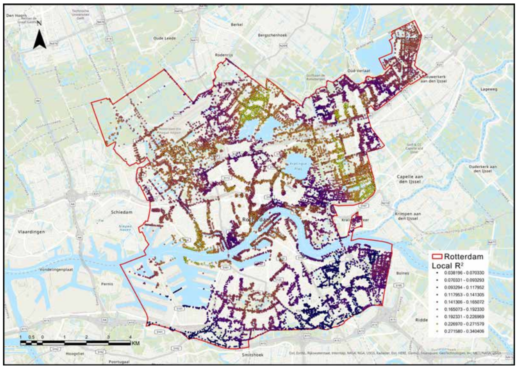


ON-WATER FACILITY

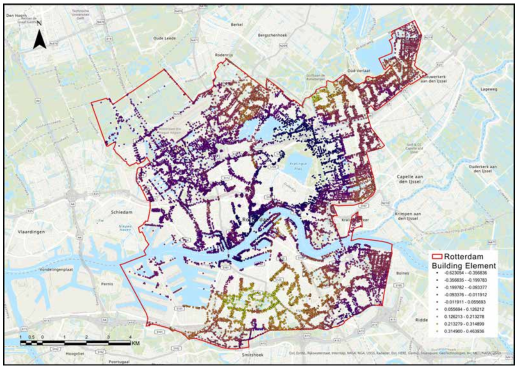


GWR Analysis Results of 35-54 Group

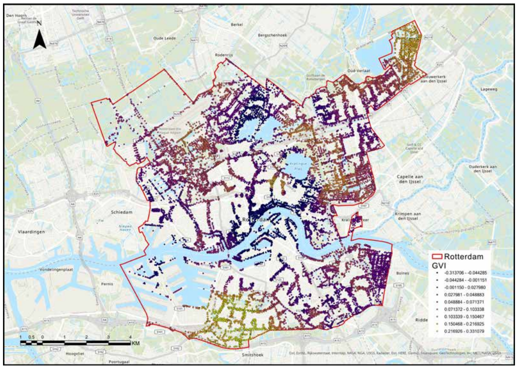
LOCAL R^2



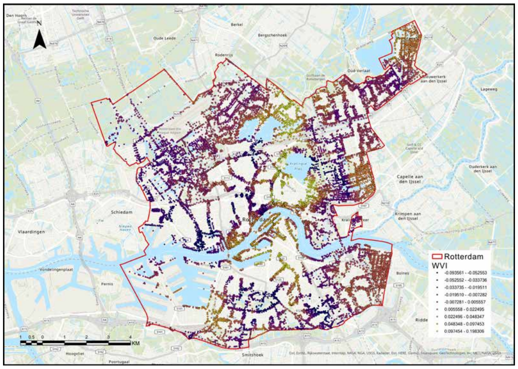
BUILDING ELEMENT



GREEN VIEW INDEX (GVI)

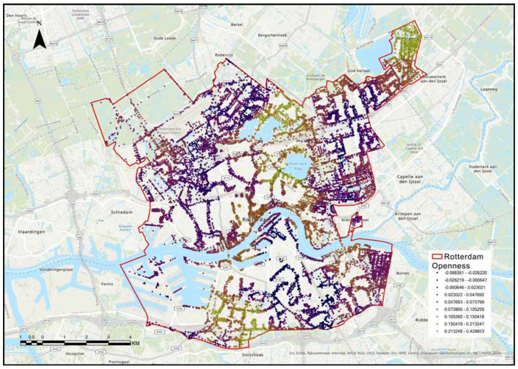


WATER VIEW INDEX (WVI)

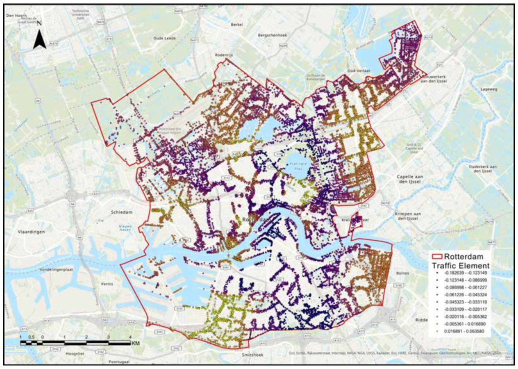


TOC

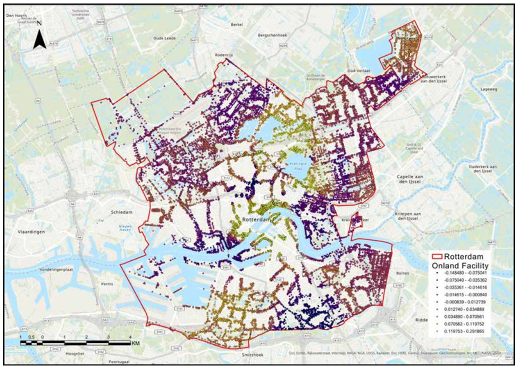
OPENNESS



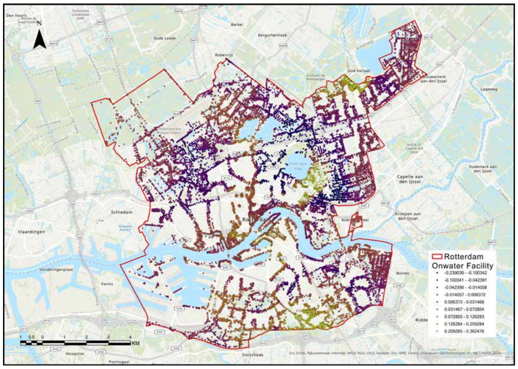
TRAFFIC ELEMENT



ON-LAND FACILITY

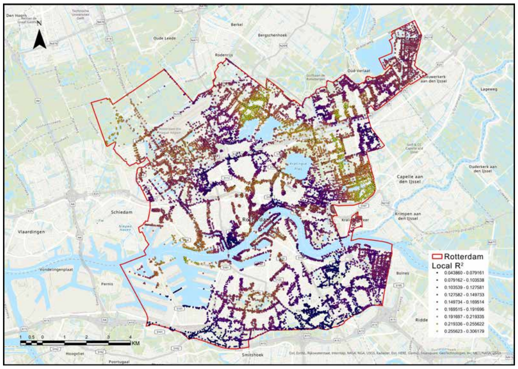


ON-WATER FACILITY

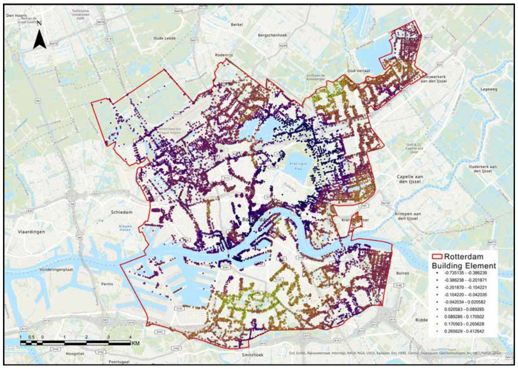


GWR Analysis Results of 55-64 Group

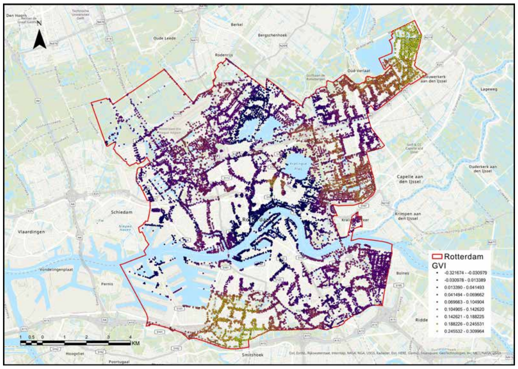
LOCAL R^2



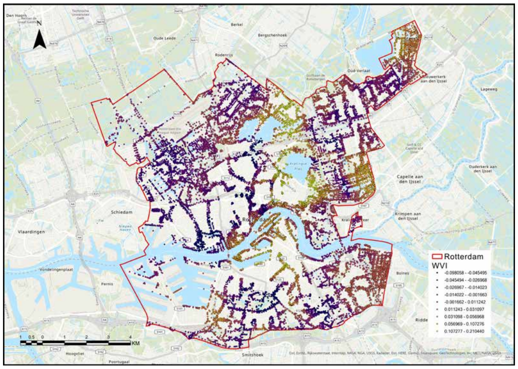
BUILDING ELEMENT



GREEN VIEW INDEX (GVI)

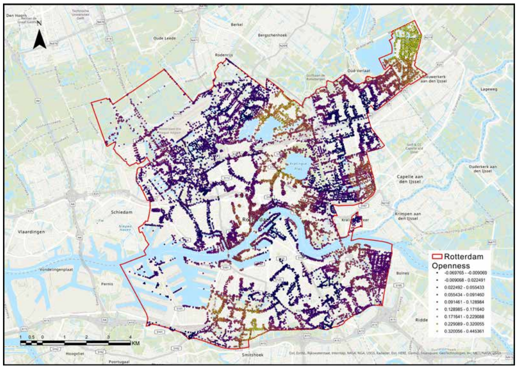


WATER VIEW INDEX (WVI)

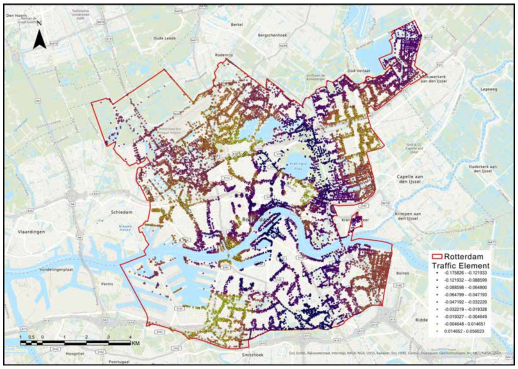


TOC

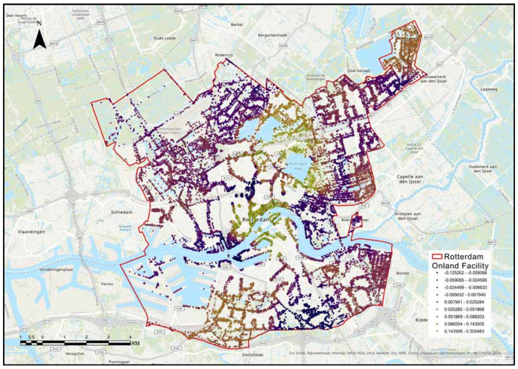
OPENNESS



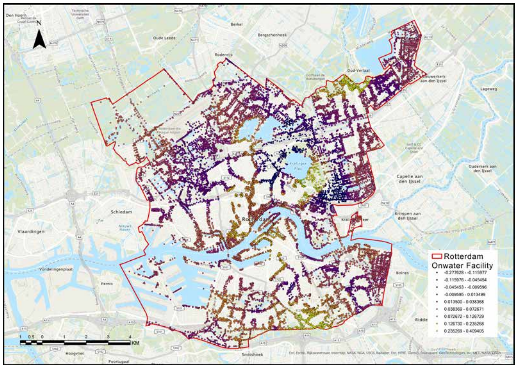
TRAFFIC ELEMENT



ON-LAND FACILITY

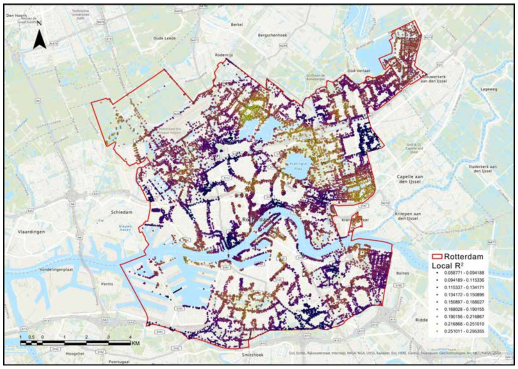


ON-WATER FACILITY

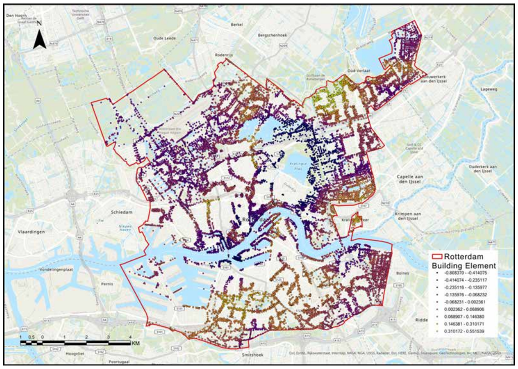


GWR Analysis Results of 65 Plus Group

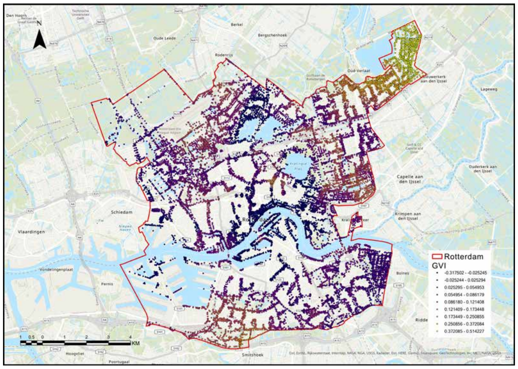
LOCAL R^2



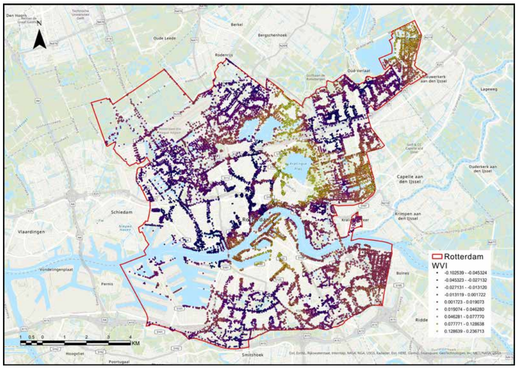
BUILDING ELEMENT



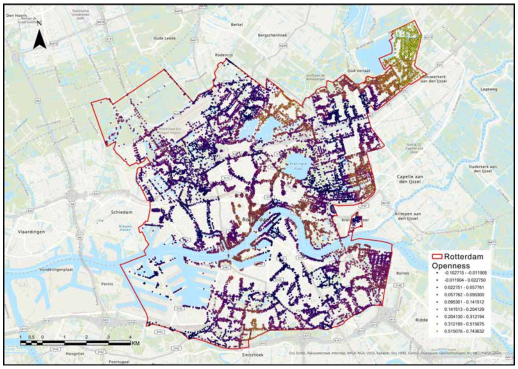
GREEN VIEW INDEX (GVI)



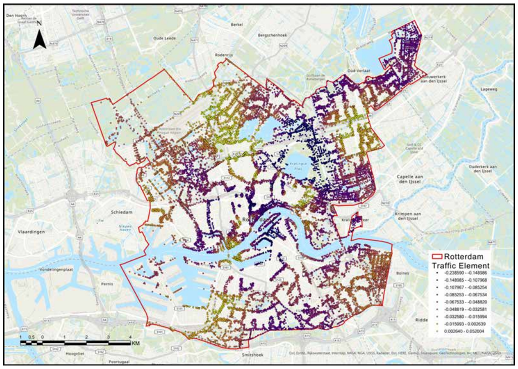
WATER VIEW INDEX (WVI)



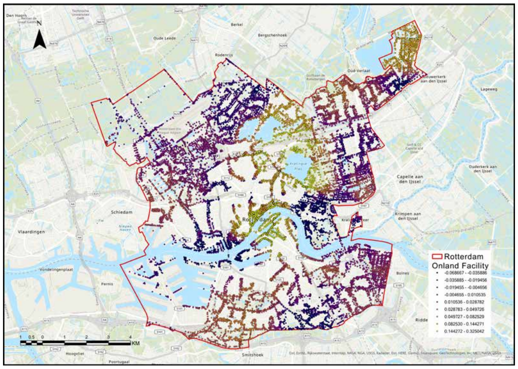
OPENNESS



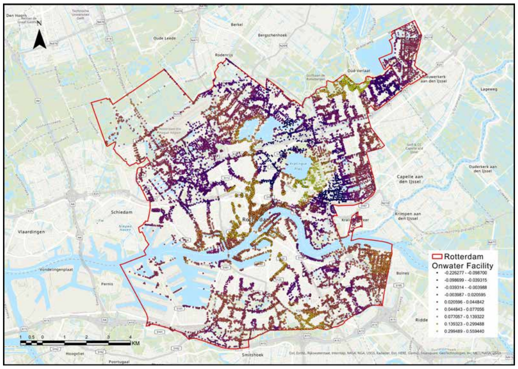
TRAFFIC ELEMENT



ON-LAND FACILITY



ON-WATER FACILITY



APPENDIX C

Post-workshop Evaluation Form

Design Principles and Spatial Patterns Related to Spatial Quantity

1 Please rate from 1 to 10 for the following statements.
The design principles and spatial patterns presented in the workshop related to spatial quantity…

- … were easy to use. (   )
- … were useful for my team's design proposal. (   )

2 Please rate the difficulty of the design principles and spatial patterns related to spatial quantity: Difficult to use (1); Neither difficult nor easy to use (2); Easy to use (3).

- Blue Space Quantity 1 – 2 - 3
- Types of Freshwater Blue Space 1 – 2 – 3

3 What did you like/dislike about the design principles and spatial patterns

4 What would you improve the design principles and spatial patterns?

Design Principles and Spatial Patterns Related to Spatial Accessibility

5 Please rate from 1 to 10 for the following statements.
The design principles and spatial patterns presented in the workshop related to spatial accessibility…

- … were easy to use. (   )
- … were useful for my team's design proposal. (   )

6 Please rate the difficulty of the design principles and spatial patterns related to spatial accessibility: Difficult to use (1); Neither difficult nor easy to use (2); Easy to use (3).

- Internal Road Design 1 – 2 - 3
- Contacting Facilities 1 – 2 - 3
- Water Edges 1 – 2 - 3
- Internal Parking Facilities 1 – 2 - 3
- Crossing Facilities 1 – 2 - 3
- Transportation Stations 1 – 2 - 3
- Walking/Cycling Route Design 1 – 2 - 3
- External Parking Facilities 1 – 2 - 3

7 What did you like/dislike about the design principles and spatial patterns?

8 What would you improve the design principles and spatial patterns?

Design Principles and Spatial Patterns Related to Spatial Visibility

9 Please rate from 1 to 10 for the following statements.
The design principles and spatial patterns presented in the workshop related to spatial visibility…

- … were easy to use. (   )
- … were useful for my team's design proposal. (   )

10 Please rate the difficulty of the design principles and spatial patterns related to spatial visibility: Difficult to use (1); Neither difficult nor easy to use (2); Easy to use (3).

- Internal Vegetation Design 1 – 2 - 3
- Water Edges 1 – 2 - 3
- Internal Road Design 1 – 2 - 3
- Viewing Facilities 1 – 2 - 3
- Building Design 1 – 2 - 3
- External Vegetation Design 1 – 2 - 3

11 What did you like/dislike about the design principles and spatial patterns?

12 What would you improve the design principles and spatial patterns?

Design Principles and Spatial Patterns Related to Spatial Quality

13 Please rate from 1 to 10 for the following statements.
The design principles and spatial patterns presented in the workshop related to spatial quality…

- … were easy to use. (   )
- … were useful for my team's design proposal. (   )

14 Please rate the difficulty of the design principles and spatial patterns related to spatial quality: Difficult to use (1); Neither difficult nor easy to use (2); Easy to use (3).

— Running/Cycling Route Planning	1 – 2 - 3
— Internal Vegetation Design	1 – 2 - 3
— Building Elements	1 – 2 - 3
— Traffic Elements	1 – 2 - 3
— Public Facilities	1 – 2 - 3

15 What did you like/dislike about the design principles and spatial patterns?

16 What would you improve the design principles and spatial patterns?

Think of The Way The Three Categories Worked Together

17 Please rank the three categories according to your preference (with the 1st as the most liked and the 3rd as the least liked). Write the number in the brackets.

— Spatial Quantity	( )
— Spatial Accessibility	( )
— Spatial Visibility	( )
— Spatial Quality	( )

18 What categories of design principle and spatial patterns do you think can be used in conjunction with each other? Please connect the categories that might be linked together with lines.

— Spatial Quantity	Spatial Quantity
— Spatial Accessibility	Spatial Accessibility
— Spatial Visibility	Spatial Visibility
— Spatial Quality	Spatial Quality

19 Can any of principles or patterns within the three categories be left out? If yes, which one?

20 Is there something missing from the set of design principles and spatial patterns?

21 If you have any final remarks or recommendations related to the set of design principles and spatial patterns, please write them below.

References

Adlakha, D., & John, F. (2022). The future is urban: integrated planning policies can enable healthy and sustainable cities. *The Lancet Global Health*, *10*(6), e790–e791. https://doi.org/10.1016/S2214-109X(22)00211-X

Akpinar, A. (2016). How is quality of urban green spaces associated with physical activity and health? *Urban Forestry & Urban Greening*, *16*, 76–83. https://doi.org/10.1016/j.ufug.2016.01.011

Alexander, C. (1977). *A Pattern Language: Towns, Buildings, Construction*. Oxford University Press.

Andersson, E., Langemeyer, J., Borgström, S., McPhearson, T., Haase, D., Kronenberg, J., Barton, D. N., Davis, M., Naumann, S., Röschel, L., & Baró, F. (2019). Enabling green and blue infrastructure to improve contributions to human well-Being and equity in urban systems. *BioScience*, *69*(7), 566–574. https://doi.org/10.1093/biosci/biz058

Annerstedt, M., Jönsson, P., Wallergård, M., Johansson, G., Karlson, B., Grahn, P., Hansen, Å. M., & Währborg, P. (2013). Inducing physiological stress recovery with sounds of nature in a virtual reality forest — Results from a pilot study. *Physiology & Behavior*, *118*, 240–250. https://doi.org/10.1016/j.physbeh.2013.05.023

Azam, A., Ahmed, A., Wang, H., Wang, Y., & Zhang, Z. (2021). Knowledge structure and research progress in wind power generation (WPG) from 2005 to 2020 using CiteSpace based scientometric analysis. *Journal of Cleaner Production*, *295*, 126496. https://doi.org/10.1016/j.jclepro.2021.126496

Ballester, J., Quijal-Zamorano, M., Méndez Turrubiates, R. F., Pegenaute, F., Herrmann, F. R., Robine, J. M., Basagaña, X., Tonne, C., Antó, J. M., & Achebak, H. (2023). Heat-related mortality in Europe during the summer of 2022. *Nature Medicine*, *29*(7), 1857–1866. https://doi.org/10.1038/s41591-023-02419-z

Barton, J., & Pretty, J. (2010). What is the best dose of nature and green exercise for improving mental health? A multi-study analysis. *Environmental Science & Technology*, *44*(10), 3947–3955. https://doi.org/10.1021/es903183r

Basner, M., Babisch, W., Davis, A., Brink, M., Clark, C., Janssen, S., & Stansfeld, S. (2014). Auditory and non-auditory effects of noise on health. *The Lancet*, *383*(9925), 1325–1332. https://doi.org/10.1016/S0140-6736(13)61613-X

Baumeister, R. F., & Leary, M. R. (1995). The need to belong: Desire for interpersonal attachments as a fundamental human motivation. *Psychological Bulletin*, *117*(3), 497–529. https://doi.org/10.1037/0033-2909.117.3.497

Bell, S., Fleming, L. E., Grellier, J., Kuhlmann, F., Nieuwenhuijsen, M. J., & White, M. P. (2021). *Urban Blue Spaces*. Routledge. https://doi.org/10.4324/9780429056161

Bengston, D. N., Fletcher, J. O., & Nelson, K. C. (2004). Public policies for managing urban growth and protecting open space: Policy instruments and lessons learned in the United States. *Landscape and Urban Planning*, *69*(2–3), 271–286. https://doi.org/10.1016/j.landurbplan.2003.08.007

Berman, M. G., Jonides, J., & Kaplan, S. (2008). The cognitive benefits of interacting with nature. *Psychological Science*, *19*(12), 1207–1212. https://doi.org/10.1111/j.1467-9280.2008.02225.x

Bhatia, R., & Wernham, A. (2008). Integrating human health into environmental impact assessment: An unrealised opportunity for environmental health and justice. *Environmental Health Perspectives*, *116*(8), 991–1000. https://doi.org/10.1289/ehp.11132

Biljecki, F., & Ito, K. (2021). Street view imagery in urban analytics and GIS: A review. *Landscape and Urban Planning*, *215*(July), 104217. https://doi.org/10.1016/j.landurbplan.2021.104217

Blitz, A. (2021). How does the individual perception of local conditions affect cycling? An analysis of the impact of built and non-built environment factors on cycling behaviour and attitudes in an urban setting. *Travel Behaviour and Society*, *25*(May), 27–40. https://doi.org/10.1016/j.tbs.2021.05.006

BlueHealth. (2020). *BlueProfiles*. https://bluehealth.tools/category/all-blue-spaces/

Boakye, K. A., Amram, O., Schuna, J. M., Duncan, G. E., & Hystad, P. (2021). GPS-based built environment measures associated with adult physical activity. *Health & Place*, *70*(June), 102602. https://doi.org/10.1016/j.healthplace.2021.102602

Boers, S., Hagoort, K., Scheepers, F., & Helbich, M. (2018). Does residential green and blue space promote recovery in psychotic disorders? A cross-sectional study in the province of Utrecht, the Netherlands. *International Journal of Environmental Research and Public Health*, *15*(10), 2195. https://doi.org/10.3390/ijerph15102195

Bowen, K. J., & Lynch, Y. (2017). The public health benefits of green infrastructure: the potential of economic framing for enhanced decision-making. *Current Opinion in Environmental Sustainability*, *25*(August), 90–95. https://doi.org/10.1016/j.cosust.2017.08.003

Braha, D., & Maimon, O. (1997). The design process: properties, paradigms, and structure. *IEEE Transactions on Systems, Man, and Cybernetics - Part A: Systems and Humans*, *27*(2), 146–166. https://doi.org/10.1109/3468.554679

Bratman, G. N., Anderson, C. B., Berman, M. G., Cochran, B., de Vries, S., Flanders, J., Folke, C., Frumkin, H., Gross, J. J., Hartig, T., Kahn, P. H., Kuo, M., Lawler, J. J., Levin, P. S., Lindahl, T., Meyer-Lindenberg, A., Mitchell, R., Ouyang, Z., Roe, J., … Daily, G. C. (2019). Nature and mental health: An ecosystem service perspective. *Science Advances*, *5*(7). https://doi.org/10.1126/sciadv.aax0903

Britton, E., Kindermann, G., Domegan, C., & Carlin, C. (2020). Blue care: A systematic review of blue space interventions for health and wellbeing. *Health Promotion International*, *35*(1), 50–69. https://doi.org/10.1093/heapro/day103

Brownson, R. C., Colditz, G. A., & Proctor, E. K. (2018). *Dissemination and implementation research in health : translating science to practice*. https://search.ebscohost.com/login.aspx?direct=true&scope=site&db=nlebk&db=nlabk&AN=1881274

Brunner, J., & Cozens, P. (2013). "Where have all the trees gone?" Urban consolidation and the demise of urban vegetation: A case study from western Australia. *Planning Practice and Research*, *28*(2), 231–255. https://doi.org/10.1080/02697459.2012.733525

Burkart, K., Meier, F., Schneider, A., Breitner, S., Canário, P., Alcoforado, M. J., Scherer, D., & Endlicher, W. (2016). Modification of heat-related mortality in an elderly urban population by vegetation (urban green) and proximity to water (urban blue): Evidence from Lisbon, Portugal. *Environmental Health Perspectives*, *124*(7), 927–934. https://doi.org/10.1289/ehp.1409529

Burton, N. W., Khan, A., & Brown, W. J. (2012). How, where and with whom? Physical activity context preferences of three adult groups at risk of inactivity. *British Journal of Sports Medicine*, *46*(16), 1125–1131. https://doi.org/10.1136/bjsports-2011-090554

Cai, J. (2018). Design with forms as well as patterns. Design with forms as well as patterns. *A+BE | Architecture and the Built Environment*, *8*(30), 1–340. https://doi.org/10.7480/abe.2018.30.3053

Camp, C. J., Rodrigue, J. R., & Olson, K. R. (1984). Curiosity in young, middle-aged, and older adults. *Educational Gerontology*, *10*(5), 387–400. https://doi.org/10.1080/0380127840100504

Campos Ferreira, M., Dias Costa, P., Abrantes, D., Hora, J., Felício, S., Coimbra, M., & Galvão Dias, T. (2022). Identifying the determinants and understanding their effect on the perception of safety, security, and comfort by pedestrians and cyclists: A systematic review. *Transportation Research Part F: Traffic Psychology and Behaviour*, *91*(February), 136–163. https://doi.org/10.1016/j.trf.2022.10.004

CBS. (2023). *Bestand bodemgebruik*. https://www.cbs.nl/nl-nl/dossier/nederland-regionaal/geografische-data/bestand-bodemgebruik

Cerin, E., Sallis, J. F., Salvo, D., Hinckson, E., Conway, T. L., Owen, N., van Dyck, D., Lowe, M., Higgs, C., Moudon, A. V., Adams, M. A., Cain, K. L., Christiansen, L. B., Davey, R., Dygrýn, J., Frank, L. D., Reis, R., Sarmiento, O. L., Adlakha, D., … Giles-Corti, B. (2022). Determining thresholds for spatial urban design and transport features that support walking to create healthy and sustainable cities: findings from the IPEN Adult study. *The Lancet Global Health*, *10*(6), e895–e906. https://doi.org/10.1016/S2214-109X(22)00068-7

Cervero, R., Sarmiento, O. L., Jacoby, E., Gomez, L. F., & Neiman, A. (2009). Influences of built environments on walking and cycling: Lessons from Bogotá. *International Journal of Sustainable Transportation*, *3*(4), 203–226. https://doi.org/10.1080/15568310802178314

Chen, L., Lu, Y., Ye, Y., Xiao, Y., & Yang, L. (2022). Examining the association between the built environment and pedestrian volume using street view images. *Cities*, *127*, 103734. https://doi.org/10.1016/j.cities.2022.103734

Chen, Y., Chen, Y., Tu, W., & Zeng, X. (2020). Is eye-level greening associated with the use of dockless shared bicycles? *Urban Forestry and Urban Greening*, *51*(June 2019), 126690. https://doi.org/10.1016/j.ufug.2020.126690

Chen, Y., & Yuan, Y. (2020). The neighbourhood effect of exposure to blue space on elderly individuals' mental health: A case study in Guangzhou, China. *Health and Place*, *63*(May). https://doi.org/10.1016/j.healthplace.2020.102348

Cherrie, M. P. C., Wheeler, B. W., White, M. P., Sarran, C. E., & Osborne, N. J. (2015). Coastal climate is associated with elevated solar irradiance and higher 25(OH)D level. *Environment International*, *77*, 76-84. https://doi.org/10.1016/j.envint.2015.01.005

Christian, H. E., Bull, F. C., Middleton, N. J., Knuiman, M. W., Divitini, M. L., Hooper, P., Amarasinghe, A., & Giles-Corti, B. (2011). How important is the land use mix measure in understanding walking behaviour? Results from the RESIDE study. *International Journal of Behavioral Nutrition and Physical Activity*, *8*. https://doi.org/10.1186/1479-5868-8-55

Clasen, T., Schmidt, W.-P., Rabie, T., Roberts, I., & Cairncross, S. (2007). Interventions to improve water quality for preventing diarrhoea: systematic review and meta-analysis. *BMJ*, *334*(7597), 782. https://doi.org/10.1136/bmj.39118.489931.BE

Coleman, T., & Kearns, R. (2015). The role of bluespaces in experiencing place, aging and wellbeing: Insights from Waiheke Island, New Zealand. *Health and Place*, *35*, 206–217. https://doi.org/10.1016/j.healthplace.2014.09.016

Corburn, J. (2007). Reconnecting with our roots. *Urban Affairs Review*, *42*(5), 688–713. https://doi.org/10.1177/1078087406296390

Corbusier, L. (1926). *Les 5 Points d' une architecture nouvelle*. MIT Dome Archive.

Corbusier, L. (1986). *Towards a new architecture*. Courier Corporation.

Costa, C., Ha, J., & Lee, S. (2021). Spatial disparity of income-weighted accessibility in Brazilian Cities: Application of a Google Maps API. *Journal of Transport Geography*, *90*(November 2020), 102905. https://doi.org/10.1016/j.jtrangeo.2020.102905

Crouse, D. L., Balram, A., Hystad, P., Pinault, L., van den Bosch, M., Chen, H., Rainham, D., Thomson, E. M., Close, C. H., van Donkelaar, A., Martin, R. V., Ménard, R., Robichaud, A., & Villeneuve, P. J. (2018). Associations between living near water and risk of mortality among urban canadians. *Environmental Health Perspectives*, *126*(7). https://doi.org/10.1289/EHP3397

Cullen, G. (2012). *Concise Townscape*. Routledge. https://doi.org/10.4324/9780080502816

Dai, D. (2011). Racial/ethnic and socioeconomic disparities in urban green space accessibility: Where to intervene? *Landscape and Urban Planning*, *102*(4), 234–244. https://doi.org/10.1016/j.landurbplan.2011.05.002

Dai, L., Zheng, C., Dong, Z., Yao, Y., Wang, R., Zhang, X., Ren, S., Zhang, J., Song, X., & Guan, Q. (2021). Analysing the correlation between visual space and residents' psychology in Wuhan, China using street-view images and deep-learning technique. *City and Environment Interactions*, *11*, 100069. https://doi.org/10.1016/j.cacint.2021.100069

Davis, J. (2022). Epidemics, planning and the city: A special issue of planning perspectives. *Planning Perspectives*, *37*(1), 1–8. https://doi.org/10.1080/02665433.2022.2019982

de Bell, S., Graham, H., Jarvis, S., & White, P. (2017). The importance of nature in mediating social and psychological benefits associated with visits to freshwater blue space. *Landscape and Urban Planning*, *167*(May), 118–127. https://doi.org/10.1016/j.landurbplan.2017.06.003

de Graaf, R., & der Brugge, R. van. (2010). Transforming water infrastructure by linking water management and urban renewal in Rotterdam. *Technological Forecasting and Social Change*, *77*(8), 1282–1291. https://doi.org/10.1016/j.techfore.2010.03.011

de Jong, T. M. (2006). Context analysis. *Delft University of Technology*.

de Jonge, J. M. (2009). *Landscape architecture between politics and science : an integrative perspective on landscape planning and design in the network society* [Wageningen University]. https://doi.org/10.18174/14357

de Keijzer, C., Tonne, C., Sabia, S., Basagaña, X., Valentín, A., Singh-Manoux, A., Antó, J. M., Alonso, J., Nieuwenhuijsen, M. J., Sunyer, J., & Dadvand, P. (2019). Green and blue spaces and physical functioning in older adults: Longitudinal analyses of the Whitehall II study. *Environment International*, *122*, 346–356. https://doi.org/10.1016/j.envint.2018.11.046

de Vries, S., Nieuwenhuizen, W., Farjon, H., van Hinsberg, A., & Dirkx, J. (2021). In which natural environments are people happiest? Large-scale experience sampling in the Netherlands. *Landscape and Urban Planning*, *205*(October 2020), 103972. https://doi.org/10.1016/j.landurbplan.2020.103972

de Vries, S., ten Have, M., van Dorsselaer, S., van Wezep, M., Hermans, T., & de Graaf, R. (2016). Local availability of green and blue space and prevalence of common mental disorders in the Netherlands. *BJPsych Open*, *2*(6), 366–372. https://doi.org/10.1192/bjpo.bp.115.002469

de Vries, S., Verheij, R. A., Groenewegen, P. P., & Spreeuwenberg, P. (2003). Natural environments—healthy environments? An exploratory analysis of the relationship between greenspace and health. *Environment and Planning A: Economy and Space*, *35*(10), 1717–1731. https://doi.org/10.1068/a35111

Dean, J., Biglieri, S., Drescher, M., Garnett, A., Glover, T., & Casello, J. (2020). Thinking relationally about built environments and walkability: A study of adult walking behaviour in Waterloo, Ontario. *Health & Place*, *64*(April), 102352. https://doi.org/10.1016/j.healthplace.2020.102352

Dempsey, S., Devine, M. T., Gillespie, T., Lyons, S., & Nolan, A. (2018). Coastal blue space and depression in older adults. *Health and Place*, *54*(September), 110–117. https://doi.org/10.1016/j.healthplace.2018.09.002

Depledge, M. H., & Bird, W. J. (2009). The Blue Gym: Health and wellbeing from our coasts. *Marine Pollution Bulletin*, *58*(7), 947–948. https://doi.org/10.1016/j.marpolbul.2009.04.019

Desfor, G., & Jørgensen, J. (2004). Flexible urban governance. The case of Copenhagen's recent waterfront development. *European Planning Studies*, *12*(4), 479–496. https://doi.org/10.1080/0965431042000212740

Dong, L., Jiang, H., Li, W., Qiu, B., Wang, H., & Qiu, W. (2023). Assessing impacts of objective features and subjective perceptions of street environment on running amount: A case study of Boston. *Landscape and Urban Planning*, *235*(March), 104756. https://doi.org/10.1016/j.landurbplan.2023.104756

Douglas, O., Lennon, M., & Scott, M. (2017). Green space benefits for health and well-being: A life-course approach for urban planning, design and management. *Cities*, *66*, 53–62. https://doi.org/10.1016/j.cities.2017.03.011

Duhl, L. J., & Sanchez, A. K. (1999). *Healthy Cities and the City Planning Process*. World Health Organization Regional Office for Europe.

Dunn, G., Brown, R. R., Bos, J. J., & Bakker, K. (2017). The role of science-policy interface in sustainable urban water transitions: Lessons from Rotterdam. E*nvironmental Science & Policy*, *73*(November 2016), 71–79. https://doi.org/10.1016/j.envsci.2017.04.013

Durán Vian, F., Pons Izquierdo, J. J., & Serrano Martínez, M. (2021). River-city recreational interaction: A classification of urban riverfront parks and walks. *Urban Forestry and Urban Greening*, *59*. https://doi.org/10.1016/j.ufug.2021.127042

Elliott, L. R., White, M. P., Grellier, J., Rees, S. E., Waters, R. D., & Fleming, L. E. (2018). Recreational visits to marine and coastal environments in England: Where, what, who, why, and when? *Marine Policy*, *97*(March), 305–314. https://doi.org/10.1016/j.marpol.2018.03.013

Elliott, L. R., White, M. P., Taylor, A. H., & Herbert, S. (2015). Energy expenditure on recreational visits to different natural environments. *Social Science and Medicine*, *139*, 53–60. https://doi.org/10.1016/j.socscimed.2015.06.038

Emfield, A. G., & Neider, M. B. (2014). Evaluating visual and auditory contributions to the cognitive restoration effect. *Frontiers in Psychology*, *5*. https://doi.org/10.3389/fpsyg.2014.00548

Engel, G. (1977). The need for a new medical model: a challenge for biomedicine. *Science*, *196*(4286), 129–136. https://doi.org/10.1126/science.847460

Finlay, J., Franke, T., McKay, H., & Sims-Gould, J. (2015). Therapeutic landscapes and wellbeing in later life: Impacts of blue and green spaces for older adults. *Health and Place*, *34*, 97–106. https://doi.org/10.1016/j.healthplace.2015.05.001

Fischer, T. B., Muthoora, T., Chang, M., & Sharpe, C. (2021). Health impact assessment in spatial planning in England –types of application and quality of documentation. *Environmental Impact Assessment Review*, *90*, 106631. https://doi.org/10.1016/j.eiar.2021.106631

Fisher, J. C., Irvine, K. N., Bicknell, J. E., Hayes, W. M., Fernandes, D., Mistry, J., & Davies, Z. G. (2021). Perceived biodiversity, sound, naturalness and safety enhance the restorative quality and wellbeing benefits of green and blue space in a neotropical city. *Science of The Total Environment*, *755*, 143095. https://doi.org/10.1016/j.scitotenv.2020.143095

Fisher, J. E., Andersen, Z. J., Loft, S., & Pedersen, M. (2017). Opportunities and challenges within urban health and sustainable development. *Current Opinion in Environmental Sustainability*, *25*, 77–83. https://doi.org/10.1016/j.cosust.2017.08.008

Foley, R. (2015). Swimming in Ireland: Immersions in therapeutic blue space. *Health and Place*, *35*, 218–225. https://doi.org/10.1016/j.healthplace.2014.09.015

Foley, R., & Kistemann, T. (2015). Blue space geographies: Enabling health in place. *Health and Place*, *35*, 157–165. https://doi.org/10.1016/j.healthplace.2015.07.003

Forouzanfar, M. H., Afshin, A., Alexander, L. T., Biryukov, S., Brauer, M., Cercy, K., Charlson, F. J., Cohen, A. J., Dandona, L., Estep, K., Ferrari, A. J., Frostad, J. J., Fullman, N., Godwin, W. W., Griswold, M., Hay, S. I., Kyu, H. H., Larson, H. J., Lim, S. S., … Zhu, J. (2016). Global, regional, and national comparative risk assessment of 79 behavioural, environmental and occupational, and metabolic risks or clusters of risks, 1990–2015: a systematic analysis for the Global Burden of Disease Study 2015. *The Lancet*, *388*(10053), 1659–1724. https://doi.org/10.1016/S0140-6736(16)31679-8

Forsythe, A., Nadal, M., Sheehy, N., Cela-Conde, C. J., & Sawey, M. (2011). Predicting beauty: Fractal dimension and visual complexity in art. *British Journal of Psychology*, *102*(1), 49–70. https://doi.org/10.1348/000712610X498958

Fox, K. R. (1999). The influence of physical activity on mental well-being. *Public Health Nutrition*, *2*(3 A), 411–418. https://doi.org/10.1017/S1368980099000567

Frantzeskaki, N., & Tilie, N. (2014). The dynamics of urban ecosystem governance in Rotterdam, the Netherlands. *Ambio*, *43*(4), 542–555. https://doi.org/10.1007/s13280-014-0512-0

Fraser, S. D. S., & Lock, K. (2011). Cycling for transport and public health: a systematic review of the effect of the environment on cycling. *European Journal of Public Health*, *21*(6), 738–743. https://doi.org/10.1093/eurpub/ckq145

Frumkin, H., Bratman, G. N., Breslow, S. J., Cochran, B., Kahn, P. H., Lawler, J. J., Levin, P. S., Tandon, P. S., Varanasi, U., Wolf, K. L., & Wood, S. A. (2017). Nature contact and human health: A research agenda. *Environmental Health Perspectives*, *125*(7), 1–18. https://doi.org/10.1289/EHP1663

Gaisberger, M., Šanović, R., Dobias, H., Kolarž, P., Moder, A., Thalhamer, J., Selimović, A., Huttegger, I., Ritter, M., & Hartl, A. (2012). Effects of ionised waterfall aerosol on pediatric allergic asthma. *Journal of Asthma*, *49*(8), 830–838. https://doi.org/10.3109/02770903.2012.705408

Gardner, W., Mulvey, E. P., & Shaw, E. C. (1995). Regression analyses of counts and rates: Poisson, overdispersed Poisson, and negative binomial models. *Psychological Bulletin*, *118*(3), 392–404. https://doi.org/10.1037/0033-2909.118.3.392

Garrett, J. K., White, M. P., Huang, J., Ng, S., Hui, Z., Leung, C., Tse, L. A., Fung, F., Elliott, L. R., Depledge, M. H., & Wong, M. C. S. (2019). Urban blue space and health and wellbeing in Hong Kong: Results from a survey of older adults. *Health & Place*, *55*(November 2018), 100–110. https://doi.org/10.1016/j.healthplace.2018.11.003

Gascon, M., Mas, M. T., Martínez, D., Dadvand, P., Forns, J., Plasència, A., & Nieuwenhuijsen, M. J. (2015). Mental health benefits of long-term exposure to residential green and blue spaces: A systematic review. *International Journal of Environmental Research and Public Health*, *12*(4), 4354–4379. https://doi.org/10.3390/ijerph120404354

Gascon, M., Sánchez-Benavides, G., Dadvand, P., Martínez, D., Gramunt, N., Gotsens, X., Cirach, M., Vert, C., Molinuevo, J. L., Crous-Bou, M., & Nieuwenhuijsen, M. (2018). Long-term exposure to residential green and blue spaces and anxiety and depression in adults: A cross-sectional study. *Environmental Research*, *162*(January), 231–239. https://doi.org/10.1016/j.envres.2018.01.012

Gascon, M., Zijlema, W., Vert, C., White, M. P., & Nieuwenhuijsen, M. J. (2017). Outdoor blue spaces, human health and well-being: A systematic review of quantitative studies. *International Journal of Hygiene and Environmental Health*, *220*(8), 1207–1221. https://doi.org/10.1016/j.ijheh.2017.08.004

Gehl, J. (2013). *Cities for people*. Island press.

Gell-Mann, M., & Mermin, D. (1994). The quark and the jaguar: Adventures in the simple and the complex. *Physics Today*, *47*(9), 89–89. https://doi.org/10.1063/1.2808634

Gerstenberg, T., Baumeister, C. F., Schraml, U., & Plieninger, T. (2020). Hot routes in urban forests: The impact of multiple landscape features on recreational use intensity. *Landscape and Urban Planning*, *203*(May), 103888. https://doi.org/10.1016/j.landurbplan.2020.103888

Gesler, W. M. (1992). Therapeutic landscapes: Medical issues in light of the new cultural geography. *Social Science and Medicine*, *34*(7), 735–746. https://doi.org/10.1016/0277-9536(92)90360-3

Gesler, W. M. (1998). Bath's reputation as a healing place. In *Putting health into place*. Syracuse University Press.

Gidlow, C. J., Jones, M. V., Hurst, G., Masterson, D., Clark-Carter, D., Tarvainen, M. P., Smith, G., & Nieuwenhuijsen, M. (2016). Where to put your best foot forward: Psycho-physiological responses to walking in natural and urban environments. *Journal of Environmental Psychology*, *45*, 22–29. https://doi.org/10.1016/j.jenvp.2015.11.003

Gidlow, C. J., Randall, J., Gillman, J., Smith, G. R., & Jones, M. V. (2016). Natural environments and chronic stress measured by hair cortisol. *Landscape and Urban Planning*, *148*, 61–67. https://doi.org/10.1016/j.landurbplan.2015.12.009

Giles-Corti, B., Vernez-Moudon, A., Reis, R., Turrell, G., Dannenberg, A. L., Badland, H., Foster, S., Lowe, M., Sallis, J. F., Stevenson, M., & Owen, N. (2016). City planning and population health: a global challenge. *The Lancet*, *388*(10062), 2912–2924. https://doi.org/https://doi.org/10.1016/S0140-6736(16)30066-6

Glanville, R. (2014). The sometimes uncomfortable marriages of design and research. In *The Routledge Companion to Design Research* (pp. 9–22). Routledge. https://doi.org/10.4324/9781315758466-3

Grafetstätter, C., Gaisberger, M., Prossegger, J., Ritter, M., Kolarž, P., Pichler, C., Thalhamer, J., & Hartl, A. (2017). Does waterfall aerosol influence mucosal immunity and chronic stress? A randomised controlled clinical trial. *Journal of Physiological Anthropology*, *36*(1), 10. https://doi.org/10.1186/s40101-016-0117-3

Grahn, P., & Stigsdotter, U. A. (2003). Landscape planning and stress. *Urban Forestry & Urban Greening*, *2*(1), 1–18.

Grellier, J., White, M. P., Albin, M., Bell, S., Elliott, L. R., Gascón, M., Gualdi, S., Mancini, L., Nieuwenhuijsen, M. J., Sarigiannis, D. A., Van Den Bosch, M., Wolf, T., Wuijts, S., & Fleming, L. E. (2017). BlueHealth: A study programme protocol for mapping and quantifying the potential benefits to public health and well-being from Europe's blue spaces. *BMJ Open*, *7*(6), 1–10. https://doi.org/10.1136/bmjopen-2017-016188

Grow, H. M., Saelens, B. E., Kerr, J., Durant, N. H., Norman, G. J., & Sallis, J. F. (2008). Where are youth active? Roles of proximity, active transport, and built environment. *Medicine & Science in Sports & Exercise*, *40*(12), 2071–2079. https://doi.org/10.1249/MSS.0b013e3181817baa

Gunawardena, K. R., Wells, M. J., & Kershaw, T. (2017). Utilising green and bluespace to mitigate urban heat island intensity. *Science of the Total Environment*, *584–585*, 1040–1055. https://doi.org/10.1016/j.scitotenv.2017.01.158

Haase, D. (2015). Reflections about blue ecosystem services in cities. *Sustainability of Water Quality and Ecology*, *5*, 77–83. https://doi.org/10.1016/j.swaqe.2015.02.003

Haase, D., Schwarz, N., Strohbach, M., Kroll, F., & Seppelt, R. (2012). Synergies, trade-offs, and losses of ecosystem services in urban regions: An integrated multiscale framework applied to the leipzig-halle region, Germany. *Ecology and Society*, *17*(3). https://doi.org/10.5751/ES-04853-170322

Hallal, P. C., Andersen, L. B., Bull, F. C., Guthold, R., Haskell, W., Ekelund, U., Alkandari, J. R., Bauman, A. E., Blair, S. N., Brownson, R. C., Craig, C. L., Goenka, S., Heath, G. W., Inoue, S., Kahlmeier, S., Katzmarzyk, P. T., Kohl, H. W., Lambert, E. V., Lee, I. M., … Wells, J. C. (2012). Global physical activity levels: Surveillance progress, pitfalls, and prospects. *The Lancet*, *380*(9838), 247–257. https://doi.org/10.1016/S0140-6736(12)60646-1

Han, K.-T. (2003). A reliable and valid self-rating measure of the restorative quality of natural environments. *Landscape and Urban Planning*, *64*(4), 209–232. https://doi.org/10.1016/S0169-2046(02)00241-4

Hartig, T., & Kahn, P. H. (2016). Living in cities, naturally. *Science*, *352*(6288), 938–940. https://doi.org/10.1126/science.aaf3759

Hartig, T., Mitchell, R., De Vries, S., & Frumkin, H. (2014). Nature and health. *Annual Review of Public Health*, *35*, 207–228. https://doi.org/10.1146/annurev-publhealth-032013-182443

Hedblom, M., Gunnarsson, B., Iravani, B., Knez, I., Schaefer, M., Thorsson, P., & Lundström, J. N. (2019). Reduction of physiological stress by urban green space in a multisensory virtual experiment. *Scientific Reports*, *9*(1), 1–11. https://doi.org/10.1038/s41598-019-46099-7

Helbich, M., Yao, Y., Liu, Y., Zhang, J., Liu, P., & Wang, R. (2019). Using deep learning to examine street view green and blue spaces and their associations with geriatric depression in Beijing, China. *Environment International*, *126*(January), 107–117. https://doi.org/10.1016/j.envint.2019.02.013

Higgins, S. L., Thomas, F., Goldsmith, B., Brooks, S. J., Hassall, C., Harlow, J., Stone, D., Völker, S., & White, P. (2019). Urban freshwaters, biodiversity, and human health and well-being: Setting an interdisciplinary research agenda. *WIREs Water*, *6*(2). https://doi.org/10.1002/wat2.1339

Hillier, B. (2007). *Space is the machine: A configurational theory of architecture*. Space Syntax.

Hillier, B., Penn, A., Hanson, J., Grajewski, T., & Xu, J. (1993). Natural movement: or, configuration and attraction in urban pedestrian movement. *Environment and Planning B: Planning and Design*, *20*(1), 29–66. https://doi.org/10.1068/b200029

Hooyberg, A., Roose, H., Grellier, J., Elliott, L. R., Lonneville, B., White, M. P., Michels, N., De Henauw, S., Vandegehuchte, M., & Everaert, G. (2020). General health and residential proximity to the coast in Belgium: Results from a cross-sectional health survey. *Environmental Research*, *184*, 109225. https://doi.org/10.1016/j.envres.2020.109225

Hossu, C. A., Iojă, I.-C., Onose, D. A., Niță, M. R., Popa, A.-M., Talabă, O., & Inostroza, L. (2019). Ecosystem services appreciation of urban lakes in Romania. Synergies and trade-offs between multiple users. *Ecosystem Services*, *37*, 100937. https://doi.org/10.1016/j.ecoser.2019.100937

Howard, E. (1965). *Garden cities of tomorrow* (Vol. 23). Mit Press.

Hua, J., Cai, M., Shi, Y., Ren, C., Xie, J., Chung, L. C. H., Lu, Y., Chen, L., Yu, Z., & Webster, C. (2022). Investigating pedestrian-level greenery in urban forms in a high-density city for urban planning. *Sustainable Cities and Society*, *80*(October 2021), 103755. https://doi.org/10.1016/j.scs.2022.103755

Huang, D., Jiang, B., & Yuan, L. (2022). Analysing the effects of nature exposure on perceived satisfaction with running routes: An activity path-based measure approach. *Urban Forestry & Urban Greening*, *68*(October 2021), 127480. https://doi.org/10.1016/j.ufug.2022.127480

Huang, D., Kyttä, M., Kajosaari, A., Xie, X., & Zhang, J. (2023). One approach does not fit all settings: Exploring the effects of natural and built environments on running pleasantness across places. *Building and Environment*, *245*(July). https://doi.org/10.1016/j.buildenv.2023.110961

Huang, D., Tian, M., & Yuan, L. (2023). Sustainable design of running friendly streets: Environmental exposures predict runnability by Volunteered Geographic Information and multilevel model approaches. *Sustainable Cities and Society*, *89*, 104336. https://doi.org/10.1016/j.scs.2022.104336

Hunter, R. F., Nieuwenhuijsen, M., Fabian, C., Murphy, N., O'Hara, K., Rappe, E., Sallis, J. F., Lambert, E. V., Duenas, O. L. S., Sugiyama, T., & Kahlmeier, S. (2023). Advancing urban green and blue space contributions to public health. *The Lancet Public Health*, *8*(9), e735–e742. https://doi.org/10.1016/S2468-2667(23)00156-1

IFLA. (2020). *The Profession of Landscape Architect*. International Federation of Landscape Architects. https://iflaeurope.eu/index.php/site/general/landscape-architecture-profession

Jacobs, J. (1961). *The death and life of great American cities*. Random House.

Jansen, M., Kamphuis, C. B. M., Pierik, F. H., Ettema, D. F., & Dijst, M. J. (2018). Neighbourhood-based PA and its environmental correlates: a GIS- and GPS based cross-sectional study in the Netherlands. *BMC Public Health*, *18*(1), 233. https://doi.org/10.1186/s12889-018-5086-5

Durand, J-N-L. (1805). *Précis des leçons d'architecture données à l'École royale polytechnique*. À Paris, Chez l'Auteur.

Jeon, J., & Woo, A. (2023). Deep learning analysis of street panorama images to evaluate the streetscape walkability of neighborhoods for subsidised families in Seoul, Korea. *Landscape and Urban Planning*, *230*, 104631. https://doi.org/10.1016/j.landurbplan.2022.104631

Jeon, J. Y., Lee, P. J., You, J., & Kang, J. (2010). Perceptual assessment of quality of urban soundscapes with combined noise sources and water sounds. *The Journal of the Acoustical Society of America*, *127*(3), 1357–1366. https://doi.org/10.1121/1.3298437

Jiang, H., Dong, L., & Qiu, B. (2022). How are macro-scale and micro-scale built environments associated with running activity? The application of Strava data and deep learning in inner London. *ISPRS International Journal of Geo-Information*, *11*(10), 504. https://doi.org/10.3390/ijgi11100504

Jones, J. C. (1992). *Design methods*. John Wiley & Sons.

Jones, O. A. H., Voulvoulis, N., & Lester, J. N. (2004). Potential ecological and human health risks associated with the presence of pharmaceutically active compounds in the aquatic environment. *Critical Reviews in Toxicology*, *34*(4), 335–350. https://doi.org/10.1080/10408440490464697

Kaplan, R., & Kaplan, S. (1989). *The experience of nature: A psychological perspective*. Cambridge university press.

Kearns, R. A., & Gesler, W. M. (1998). *Putting health into place: landscape, identity, and well-being*. Syracuse University Press.

Kerr, J., Emond, J. A., Badland, H., Reis, R., Sarmiento, O., Carlson, J., Sallis, J. F., Cerin, E., Cain, K., Conway, T., Schofield, G., Macfarlane, D. J., Christiansen, L. B., Van Dyck, D., Davey, R., Aguinaga-Ontoso, I., Salvo, D., Sugiyama, T., Owen, N., … Natarajan, L. (2016). Perceived neighbourhood environmental attributes associated with walking and cycling for transport among adult residents of 17 cities in 12 countries: The IPEN study. *Environmental Health Perspectives*, *124*(3), 290–298. https://doi.org/10.1289/ehp.1409466

Ki, D., & Lee, S. (2021). Analysing the effects of Green View Index of neighborhood streets on walking time using Google Street View and deep learning. *Landscape and Urban Planning*, *205*(June 2020), 103920. https://doi.org/10.1016/j.landurbplan.2020.103920

Kim, G., Kim, A., & Kim, Y. (2019). A new 3D space syntax metric based on 3D isovist capture in urban space using remote sensing technology. *Computers, Environment and Urban Systems*, *74*, 74–87. https://doi.org/10.1016/j.compenvurbsys.2018.11.009

Kim, H. (2015). Walking distance, route choice, and activities while walking: A record of following pedestrians from transit stations in the San Francisco Bay area. *URBAN DESIGN International*, *20*(2), 144–157. https://doi.org/10.1057/udi.2015.2

Klepeis, N. E., Nelson, W. C., Ott, W. R., Robinson, J. P., Tsang, A. M., Switzer, P., Behar, J. V, Hern, S. C., & Engelmann, W. H. (2001). The national human activity pattern survey (NHAPS): A resource for assessing exposure to environmental pollutants. *Journal of Exposure Science & Environmental Epidemiology*, *11*(3), 231–252. https://doi.org/10.1038/sj.jea.7500165

Knight, S. J., McClean, C. J., & White, P. C. L. (2022). The importance of ecological quality of public green and blue spaces for subjective well-being. *Landscape and Urban Planning*, *226*, 104510. https://doi.org/10.1016/j.landurbplan.2022.104510

Kondo, M. C., South, E. C., & Branas, C. C. (2015). Nature-based strategies for improving urban health and safety. *Journal of Urban Health*, *92*(5), 800–814. https://doi.org/10.1007/s11524-015-9983-y

Konijnendijk, C. C. (2023). Evidence-based guidelines for greener, healthier, more resilient neighbourhoods: Introducing the 3–30–300 rule. *Journal of Forestry Research*, *34*(3), 821–830. https://doi.org/10.1007/s11676-022-01523-z

Koo, B. W., Guhathakurta, S., & Botchwey, N. (2022). How are neighbourhood and street-level walkability factors associated with walking behaviours? A big data approach using street view images. *Environment and Behavior*, *54*(1), 211–241. https://doi.org/10.1177/00139165211014609

Koohsari, M. J., Oka, K., Owen, N., & Sugiyama, T. (2019). Natural movement: A space syntax theory linking urban form and function with walking for transport. *Health & Place*, *58*(October 2018), 102072. https://doi.org/10.1016/j.healthplace.2019.01.002

Koohsari, M. J., Sugiyama, T., Mavoa, S., Villanueva, K., Badland, H., Giles-Corti, B., & Owen, N. (2016). Street network measures and adults' walking for transport: Application of space syntax. *Health & Place*, *38*, 89–95. https://doi.org/10.1016/j.healthplace.2015.12.009

Kovats, R. S., & Hajat, S. (2008). Heat stress and public health: A critical review. *Annual Review of Public Health*, *29*, 41–55. https://doi.org/10.1146/annurev.publhealth.29.020907.090843

Krukar, J., Manivannan, C., Bhatt, M., & Schultz, C. (2021). Embodied 3D isovists: A method to model the visual perception of space. *Environment and Planning B: Urban Analytics and City Science*, *48*(8), 2307–2325. https://doi.org/10.1177/2399808320974533

Kummu, M., de Moel, H., Ward, P. J., & Varis, O. (2011). How close do we live to water? A global analysis of population distance to freshwater bodies. *PLoS ONE*, *6*(6). https://doi.org/10.1371/journal.pone.0020578

Labib, S. M., Lindley, S., & Huck, J. J. (2020). Spatial dimensions of the influence of urban green-blue spaces on human health: A systematic review. *Environmental Research*, *180*(October 2019), 108869. https://doi.org/10.1016/j.envres.2019.108869

Laddu, D., Paluch, A. E., & LaMonte, M. J. (2021). The role of the built environment in promoting movement and physical activity across the lifespan: Implications for public health. *Progress in Cardiovascular Diseases*, *64*, 33–40. https://doi.org/10.1016/j.pcad.2020.12.009

Lahariya, C. (2008). The State of the World Population 2007: Unleashing the potential of urban growth. *Indian Pediatrics*, *45*(6), 481–482.

Laumann, K., Garling, T., & Stormark, K. M. (2001). Rating scale measures of restorative components of environments. *Journal of Environmental Psychology*, *21*(1), 31–44. https://doi.org/10.1006/jevp.2000.0179

Law, S., Sakr, F., & Martinez, M. (2014). Measuring the changes in aggregate cycling patterns between 2003 and 2012 from a space syntax perspective. *Behavioral Sciences*, *4*(3), 278–300. https://doi.org/10.3390/bs4030278

Lee, K., & Sener, I. N. (2021). Strava Metro data for bicycle monitoring: a literature review. *Transport Reviews*, *41*(1), 27–47. https://doi.org/10.1080/01441647.2020.1798558

Lengen, C., & Kistemann, T. (2012). Sense of place and place identity: Review of neuroscientific evidence. *Health and Place*, *18*(5), 1162–1171. https://doi.org/10.1016/j.healthplace.2012.01.012

Levy-Storms, L., Chen, L., & Loukaitou-Sideris, A. (2018). Older adults' needs and preferences for open space and physical activity in and near parks: A systematic review. *Journal of Aging and Physical Activity*, *26*(4), 682–696. https://doi.org/10.1123/japa.2016-0354

Li, L., Du, Q., Ren, F., & Ma, X. (2019). Assessing spatial accessibility to hierarchical urban parks by multi-types of travel distance in Shenzhen, China. *International Journal of Environmental Research and Public Health*, *16*(6), 1038. https://doi.org/10.3390/ijerph16061038

Li, Q., Kobayashi, M., Inagaki, H., Hirata, Y., Li, Y. J., Hirata, K., Shimizu, T., Suzuki, H., Katsumata, M., Wakayama, Y., Kawada, T., Ohira, T., Matsui, N., & Kagawa, T. (2010). A day trip to a forest park increases human natural killer activity and the expression of anti-cancer proteins in male subjects. *Journal of Biological Regulators and Homeostatic Agents*, *24*(2), 157–165. http://www.ncbi.nlm.nih.gov/pubmed/20487629

Liang, H., Yan, Q., Yan, Y., & Zhang, Q. (2023). Using an improved 3SFCA method to assess inequities associated with multimodal accessibility to green spaces based on mismatches between supply and demand in the metropolitan of Shanghai, China. *Sustainable Cities and Society*, *91*(February), 104456. https://doi.org/10.1016/j.scs.2023.104456

Liu, J., Ettema, D., & Helbich, M. (2023). Street view environments are associated with the walking duration of pedestrians: The case of Amsterdam, the Netherlands. *Landscape and Urban Planning*, *235*(March), 104752. https://doi.org/10.1016/j.landurbplan.2023.104752

Liu, K., Siu, K. W. M., Gong, X. Y., Gao, Y., & Lu, D. (2016). Where do networks really work? The effects of the Shenzhen greenway network on supporting physical activities. *Landscape and Urban Planning*, *152*, 49–58. https://doi.org/10.1016/j.landurbplan.2016.04.001

Liu, M. (2020). *Mapping Landscape Spaces characteristics in landscape design. A+BE | Architecture and the Built Environment*, *10*(20), 1–248. https://doi.org/10.7480/abe.2020.20.5403

Liu, M., & Nijhuis, S. (2020). Mapping landscape spaces: Methods for understanding spatial-visual characteristics in landscape design. *Environmental Impact Assessment Review*, *82*(June 2019), 106376. https://doi.org/10.1016/j.eiar.2020.106376

Liu, M., & Nijhuis, S. (2021). The application of advanced mapping methods and tools for spatial-visual analysis in landscape design practice. *Sustainability*, *13*(14), 7952. https://doi.org/10.3390/su13147952

Lu, Y. (2019). Using Google Street View to investigate the association between street greenery and physical activity. *Landscape and Urban Planning*, *191*(September 2018), 103435. https://doi.org/10.1016/j.landurbplan.2018.08.029

Lu, Y., Yang, Y., Sun, G., & Gou, Z. (2019). Associations between overhead-view and eye-level urban greenness and cycling behaviours. *Cities*, *88*(May 2018), 10–18. https://doi.org/10.1016/j.cities.2019.01.003

Luttik, J. (2000). The value of trees, water and open space as reflected by house prices in the Netherlands. *Landscape and Urban Planning*, *48*(3–4), 161–167. https://doi.org/10.1016/S0169-2046(00)00039-6

Ma, X., Ma, C., Wu, C., Xi, Y., Yang, R., Peng, N., Zhang, C., & Ren, F. (2021). Measuring human perceptions of streetscapes to better inform urban renewal: A perspective of scene semantic parsing. *Cities*, *110*(October 2020), 103086. https://doi.org/10.1016/j.cities.2020.103086

Ma, Y., Brindley, P., & Lange, E. (2022). A comparison of GIS-based methods for modelling walking accessibility of parks in Guangzhou considering different population groups. *Journal of Digital Landscape Architecture*, *2022*(7), 269–279. https://doi.org/10.14627/537724026

Maas, J., Verheij, R. A., de Vries, S., Spreeuwenberg, P., Schellevis, F. G., & Groenewegen, P. P. (2009). Morbidity is related to a green living environment. *Journal of Epidemiology & Community Health*, *63*(12), 967–973. https://doi.org/10.1136/jech.2008.079038

MacKerron, G., & Mourato, S. (2013). Happiness is greater in natural environments. *Global Environmental Change*, *23*(5), 992–1000. https://doi.org/10.1016/j.gloenvcha.2013.03.010

Mapar, M., Jafari, M. J., Mansouri, N., Arjmandi, R., Azizinezhad, R., & Ramos, T. B. (2020). A composite index for sustainability assessment of health, safety and environmental performance in municipalities of megacities. *Sustainable Cities and Society*, *60*(March), 102164. https://doi.org/10.1016/j.scs.2020.102164

Markevych, I., Schoierer, J., Hartig, T., Chudnovsky, A., Hystad, P., Dzhambov, A. M., de Vries, S., Triguero-Mas, M., Brauer, M., Nieuwenhuijsen, M. J., Lupp, G., Richardson, E. A., Astell-Burt, T., Dimitrova, D., Feng, X., Sadeh, M., Standl, M., Heinrich, J., & Fuertes, E. (2017). Exploring pathways linking greenspace to health: Theoretical and methodological guidance. *Environmental Research*, *158*(February), 301–317. https://doi.org/10.1016/j.envres.2017.06.028

Marquet, O., Aaron Hipp, J., Alberico, C., Huang, J.-H., Fry, D., Mazak, E., Lovasi, G. S., & Floyd, M. F. (2019). Park use preferences and physical activity among ethnic minority children in low-income neighbourhoods in New York City. *Urban Forestry & Urban Greening*, *38*(September 2018), 346–353. https://doi.org/10.1016/j.ufug.2019.01.018

Meddings, D. R., Scarr, J. P., Larson, K., Vaughan, J., & Krug, E. G. (2021). Drowning prevention: turning the tide on a leading killer. *The Lancet Public Health*, *6*(9), e692–e695. https://doi.org/10.1016/S2468-2667(21)00165-1

McDougall, C. W., Hanley, N., Quilliam, R. S., Bartie, P. J., Robertson, T., Griffiths, M., & Oliver, D. M. (2021). Neighbourhood blue space and mental health: A nationwide ecological study of antidepressant medication prescribed to older adults. *Landscape and Urban Planning*, *214*(December 2020), 104132. https://doi.org/10.1016/j.landurbplan.2021.104132

McDougall, C. W., Hanley, N., Quilliam, R. S., & Oliver, D. M. (2022). Blue space exposure, health and well-being: Does freshwater type matter? *Landscape and Urban Planning*, *224*, 104446. https://doi.org/10.1016/j.landurbplan.2022.104446

McDougall, C. W., Quilliam, R. S., Hanley, N., & Oliver, D. M. (2020). Freshwater blue space and population health: An emerging research agenda. *Science of The Total Environment*, *737*, 140196. https://doi.org/10.1016/j.scitotenv.2020.140196

Megahed, N. A., & Ghoneim, E. M. (2020). Antivirus-built environment: Lessons learned from Covid-19 pandemic. *Sustainable Cities and Society*, *61*(June), 102350. https://doi.org/10.1016/j.scs.2020.102350

Mishra, H. S., Bell, S., Grellier, J., & White, M. P. (2021). Testing the reliability and effectiveness of a new tool for assessing urban blue spaces: The BlueHealth environmental assessment tool (BEAT). *Health & Place*, *68*, 102526. https://doi.org/10.1016/j.healthplace.2021.102526

Mishra, H. S., Bell, S., Vassiljev, P., Kuhlmann, F., Niin, G., & Grellier, J. (2020). The development of a tool for assessing the environmental qualities of urban blue spaces. *Urban Forestry & Urban Greening*, *49*(June 2019), 126575. https://doi.org/10.1016/j.ufug.2019.126575

Mitchell, R. (2013). Is physical activity in natural environments better for mental health than physical activity in other environments? *Social Science and Medicine*, *91*, 130–134. https://doi.org/10.1016/j.socscimed.2012.04.012

Mitchell, R. J., Richardson, E. A., Shortt, N. K., & Pearce, J. R. (2015). Neighbourhood environments and socioeconomic inequalities in mental well-Being. *American Journal of Preventive Medicine*, *49*(1), 80–84. https://doi.org/10.1016/j.amepre.2015.01.017

Montello, D. R. (1993). Scale and multiple psychologies of space. In *Spatial information theory a theoretical basis for GIS (*pp. 571–575). Springer. https://doi.org/10.1007/3-540-57207-4_21

Moran, M., Plaut, P., & Baron-Epel, O. (2016). Do children walk where they bike? Exploring built environment correlates of children's walking and bicycling. *Journal of Transport and Land Use*, *9*(2), 43–65. https://doi.org/10.5198/jtlu.2015.556

Morello, E., & Ratti, C. (2009). A digital image of the city: 3D isovists in Lynch's urban analysis. *Environment and Planning B: Planning and Design*, *36*(5), 837–853. https://doi.org/10.1068/b34144t

Mumford, L. (1961). *The city in history: Its origins, its transformations, and its prospects.* Houghton Mifflin Harcourt.

Murrin, E., Taylor, N., Peralta, L., Dudley, D., Cotton, W., & White, R. L. (2023). Does physical activity mediate the associations between blue space and mental health? A cross-sectional study in Australia. *BMC Public Health*, *23*(1), 203. https://doi.org/10.1186/s12889-023-15101-3

Nadal, M., Munar, E., Marty, G., & Cela-Conde, C. J. (2010). Visual complexity and beauty appreciation: Explaining the divergence of results. *Empirical Studies of the Arts*, *28*(2), 173–191. https://doi.org/10.2190/EM.28.2.d

Nawrath, M., Kowarik, I., & Fischer, L. K. (2019). The influence of green streets on cycling behaviour in European cities. *Landscape and Urban Planning*, *190*(April), 103598. https://doi.org/10.1016/j.landurbplan.2019.103598

Nieuwenhuijsen, M. J., Dadvand, P., Márquez, S., Bartoll, X., Barboza, E. P., Cirach, M., Borrell, C., & Zijlema, W. L. (2022). The evaluation of the 3-30-300 green space rule and mental health. *Environmental Research*, *215*(June), 114387. https://doi.org/10.1016/j.envres.2022.114387

Nijhuis, S. (2015). GIS-based landscape design research Stourhead landscape garden as a case study. In *A+BE | Architecture and the Built Environment*, *5*(13), 1-338. https://journals.open.tudelft.nl/abe/article/view/1018

Nijhuis, S., & Bobbink, I. (2012). Design-related research in landscape architecture. *Journal of Design Research*, *10*(4), 239. https://doi.org/10.1504/JDR.2012.051172

Nijhuis, S., & de Vries, J. (2019). Design as research in landscape architecture. *Landscape Journal*, *38*(1–2), 87–103. https://doi.org/10.3368/lj.38.1-2.87

Nijhuis, S., & Jauslin, D. (2015). Urban landscape infrastructures: Designing operative landscape structures for the built environment. *Research in Urbanism Series*, *3*, 13–34. https://doi.org/10.7480/rius.3.874

Nutsford, D., Pearson, A. L., Kingham, S., & Reitsma, F. (2016). Residential exposure to visible blue space (but not green space) associated with lower psychological distress in a capital city. *Health & Place*, *39*, 70–78. https://doi.org/10.1016/j.healthplace.2016.03.002

Ode, Å., Hagerhall, C. M., & Sang, N. (2010). Analysing visual landscape complexity: Theory and application. *Landscape Research*, *35*(1), 111–131. https://doi.org/10.1080/01426390903414935

Orellana, D., & Guerrero, M. L. (2019). Exploring the influence of road network structure on the spatial behaviour of cyclists using crowdsourced data. *Environment and Planning B: Urban Analytics and City Science*, *46*(7), 1314–1330. https://doi.org/10.1177/2399808319863810

Ottoni, C. A., Sims-Gould, J., & Winters, M. (2021). Safety perceptions of older adults on an urban greenway: Interplay of the social and built environment. *Health & Place*, *70*, 102605. https://doi.org/10.1016/j.healthplace.2021.102605

Paccoud, A. (2016). Planning law, power, and practice: Haussmann in Paris (1853–1870). Planning Perspectives, 31(3), 341–361. https://doi.org/10.1080/02665433.2015.1089414

Palmer, J. F. (2022). Deconstructing viewshed analysis makes it possible to construct a useful visual impact map for wind projects. *Landscape and Urban Planning*, *225*, 104423. https://doi.org/10.1016/j.landurbplan.2022.104423

Pasanen, T. P., White, M. P., Wheeler, B. W., Garrett, J. K., & Elliott, L. R. (2019). Neighbourhood blue space, health and wellbeing: The mediating role of different types of physical activity. *Environment International*, *131*, 105016. https://doi.org/10.1016/j.envint.2019.105016

Pearson, A. L., Shortridge, A., Delamater, P. L., Horton, T. H., Dahlin, K., Rzotkiewicz, A., & Marchiori, M. J. (2019). Effects of freshwater blue spaces may be beneficial for mental health: A first, ecological study in the North American Great Lakes region. *PLOS ONE*, *14*(8), e0221977. https://doi.org/10.1371/journal.pone.0221977

Perchoux, C., Kestens, Y., Brondeel, R., & Chaix, B. (2015). Accounting for the daily locations visited in the study of the built environment correlates of recreational walking (the RECORD Cohort Study). *Preventive Medicine*, *81*, 142–149. https://doi.org/10.1016/j.ypmed.2015.08.010

Polat, A. T., & Akay, A. (2015). Relationships between the visual preferences of urban recreation area users and various landscape design elements. *Urban Forestry & Urban Greening*, *14*(3), 573–582. https://doi.org/10.1016/j.ufug.2015.05.009

Poulsen, M. N., Schwartz, B. S., DeWalle, J., Nordberg, C., Pollak, J. S., Silva, J., Mercado, C. I., Rolka, D. B., Siegel, K. R., & Hirsch, A. G. (2021). Proximity to freshwater blue space and type 2 diabetes onset: The importance of historical and economic context. *Landscape and Urban Planning*, *209*(January), 104060. https://doi.org/10.1016/j.landurbplan.2021.104060

Pucher, J., & Buehler, R. (2008). Making cycling irresistible: Lessons from the Netherlands, Denmark and Germany. *Transport Reviews*, *28*(4), 495–528. https://doi.org/10.1080/01441640701806612

Puhakka, R., Poikolainen, J., & Karisto, A. (2015). Spatial practises and preferences of older and younger people: Findings from the finnish studies. *Journal of Social Work Practice*, *29*(1), 69–83. https://doi.org/10.1080/02650533.2014.993948

Qiang, Y., Shen, S., & Chen, Q. (2019). Visibility analysis of oceanic blue space using digital elevation models. *Landscape and Urban Planning*, *181*, 92–102. https://doi.org/10.1016/j.landurbplan.2018.09.019

Qiao, X., Gu, Y., Zou, C., Xu, D., Wang, L., Ye, X., Yang, Y., & Huang, X. (2019). Temporal variation and spatial scale dependency of the trade-offs and synergies among multiple ecosystem services in the Taihu Lake Basin of China. *Science of The Total Environment*, *651*, 218–229. https://doi.org/10.1016/j.scitotenv.2018.09.135

Rahman, M. M., Najaf, P., Fields, M. G., & Thill, J.-C. (2022). Traffic congestion and its urban scale factors: Empirical evidence from American urban areas. *International Journal of Sustainable Transportation*, *16*(5), 406–421. https://doi.org/10.1080/15568318.2021.1885085

Ramaswami, A., Russell, A. G., Culligan, P. J., Rahul Sharma, K., & Kumar, E. (2016). Meta-principles for developing smart, sustainable, and healthy cities. *Science*, *352*(6288), 940–943. https://doi.org/10.1126/science.aaf7160

Rawat, K. S., & Sood, S. K. (2021). Knowledge mapping of computer applications in education using CiteSpace. *Computer Applications in Engineering Education*, *29*(5), 1324–1339. https://doi.org/10.1002/cae.22388

Remme, R. P., Frumkin, H., Guerry, A. D., King, A. C., Mandle, L., Sarabu, C., Bratman, G. N., Giles-Corti, B., Hamel, P., Han, B., Hicks, J. L., James, P., Lawler, J. J., Lindahl, T., Liu, H., Lu, Y., Oosterbroek, B., Paudel, B., Sallis, J. F., … Daily, G. C. (2021). Nature and physical activity in cities: an ecosystem service perspective. *Proceedings of the National Academy of Sciences*, *118*(22), 1–10. https://doi.org/10.1073/pnas.2018472118

Ren, C., Yang, R., Cheng, C., Xing, P., Fang, X., Zhang, S., Wang, H., Shi, Y., Zhang, X., Kwok, Y. T., & Ng, E. (2018). Creating breathing cities by adopting urban ventilation assessment and wind corridor plan – The implementation in Chinese cities. *Journal of Wind Engineering and Industrial Aerodynamics*, *182*(September), 170–188. https://doi.org/10.1016/j.jweia.2018.09.023

Rijkswaterstaat. (2023). *Nieuwe Maas*. Vaarwegenoverzicht. https://www.rijkswaterstaat.nl/water/vaarwegenoverzicht/nieuwe-maas

Rook, G. A. (2013). Regulation of the immune system by biodiversity from the natural environment: An ecosystem service essential to health. *Proceedings of the National Academy of Sciences of the United States of America*, *110*(46), 18360–18367. https://doi.org/10.1073/pnas.1313731110

Rose, G. (1985). Sick individuals and sick populations. *International Journal of Epidemiology*, *14*(1), 32–38. https://doi.org/10.1093/ije/14.1.32

Rothfeld, R., Straubinger, A., Paul, A., & Antoniou, C. (2019). Analysis of European airports' access and egress travel times using Google Maps. *Transport Policy*, *81*(April 2018), 148–162. https://doi.org/10.1016/j.tranpol.2019.05.021

Rowe, P. G. (1987). *Design Thinking*. MIT press.

Ruzickova, K., Ruzicka, J., & Bitta, J. (2021). A new GIS-compatible methodology for visibility analysis in digital surface models of earth sites. *Geoscience Frontiers*, *12*(4), 101109. https://doi.org/10.1016/j.gsf.2020.11.006

Rydin, Y., Bleahu, A., Davies, M., Dávila, J. D., Friel, S., De Grandis, G., Groce, N., Hallal, P. C., Hamilton, I., Howden-Chapman, P., Lai, K. M., Lim, C. J., Martins, J., Osrin, D., Ridley, I., Scott, I., Taylor, M., Wilkinson, P., & Wilson, J. (2012). Shaping cities for health: Complexity and the planning of urban environments in the 21st century. *The Lancet*, *379*(9831), 2079–2108. https://doi.org/10.1016/S0140-6736(12)60435-8

Samet, J. M., Dominici, F., Curriero, F. C., Coursac, I., & Zeger, S. L. (2000). Fine particulate air pollution and mortality in 20 U.S. cities, 1987–1994. *New England Journal of Medicine*, *343*(24), 1742–1749. https://doi.org/10.1056/NEJM200012143432401

Sarkar, C., & Webster, C. (2017). Urban environments and human health: current trends and future directions. *Current Opinion in Environmental Sustainability*, *25*, 33–44. https://doi.org/10.1016/j.cosust.2017.06.001

Secor, A. J. (2010). Social surveys, interviews, and focus groups. *Research Methods in Geography: A Critical Introduction*, *6*, 194–205.
Shanahan, D. F., Lin, B. B., Bush, R., Gaston, K. J., Dean, J. H., Barber, E., & Fuller, R. A. (2015). Toward improved public health outcomes from urban nature. *American Journal of Public Health*, *105*(3), 470–477. https://doi.org/10.2105/AJPH.2014.302324
Sharifi, F., Nygaard, A., & Stone, W. M. (2021). Heterogeneity in the subjective well-being impact of access to urban green space. *Sustainable Cities and Society*, *74*(February), 103244. https://doi.org/10.1016/j.scs.2021.103244
Sharmin, S., & Kamruzzaman, M. (2018). Meta-analysis of the relationships between space syntax measures and pedestrian movement. *Transport Reviews*, *38*(4), 524–550. https://doi.org/10.1080/01441647.2017.1365101
Shiffrin, R. M., & Börner, K. (2004). Mapping knowledge domains. *Proceedings of the National Academy of Sciences of the United States of America*, *101*(SUPPL. 1), 5183–5185. https://doi.org/10.1073/pnas.0307852100
Sinclair, R. G., Jones, E. L., & Gerba, C. P. (2009). Viruses in recreational water-borne disease outbreaks: a review. *Journal of Applied Microbiology*, *107*(6), 1769–1780. https://doi.org/10.1111/j.1365-2672.2009.04367.x
Smith, N., Georgiou, M., King, A. C., Tieges, Z., Webb, S., & Chastin, S. (2021). Urban blue spaces and human health: A systematic review and meta-analysis of quantitative studies. *Cities*, *119*(November 020), 103413. https://doi.org/10.1016/j.cities.2021.103413
Solomon, S. (2010). *Water: The epic struggle for wealth, power, and civilisation*. Harper Collins.
Song, Y., Chen, B., Ho, H. C., Kwan, M.-P., Liu, D., Wang, F., Wang, J., Cai, J., Li, X., Xu, Y., He, Q., Wang, H., Xu, Q., & Song, Y. (2021). Observed inequality in urban greenspace exposure in China. *Environment International*, *156*(January), 106778. https://doi.org/10.1016/j.envint.2021.106778
Spengler, J. O., Floyd, M. F., Maddock, J. E., Gobster, P. H., Suau, L. J., & Norman, G. J. (2011). Correlates of park-based physical activity among children in diverse communities: Results from an observational study in two cities. *American Journal of Health Promotion*, *25*(5), e1–e9. https://doi.org/10.4278/ajhp.090211-QUAN-58
Steenbergen, C. M., Meeks, S., & Nijhuis, S. (2008). *Composing landscapes: Analysis, typology and experiments for design*. Birkhäuser Basel.
Steinitz, C. (1990). A framework for theory applicable to the education of landscape architects (and other environmental design professionals). *Landscape Journal*, *9*(2), 136–143. https://doi.org/10.3368/lj.9.2.136
Steinitz, C. (1995). Design is a verb; Design is a noun. *Landscape Journal*, *14*(2), 188–200. https://doi.org/10.3368/lj.14.2.188
Steinitz, C. (2012). *A framework for geodesign: Changing geography by design*. ESRI Press.
Stronegger, W. J., Titze, S., & Oja, P. (2010). Perceived characteristics of the neighbourhood and its association with physical activity behaviour and self-rated health. *Health and Place*, *16*(4), 736–743. https://doi.org/10.1016/j.healthplace.2010.03.005
Su, S., Li, Z., Xu, M., Cai, Z., & Weng, M. (2017). A geo-big data approach to intra-urban food deserts: Transit-varying accessibility, social inequalities, and implications for urban planning. *Habitat International*, *64*, 22–40. https://doi.org/10.1016/j.habitatint.2017.04.007
Sugiyama, T., & Ward Thompson, C. (2007). Older people's health, outdoor activity and supportiveness of neighbourhood environments. *Landscape and Urban Planning*, *83*(2–3), 168–175. https://doi.org/10.1016/j.landurbplan.2007.04.002
Susser, M., & Susser, E. (1996). Choosing a future for epidemiology: I. Eras and paradigms. *American Journal of Public Health*, *86*(5), 668–673. https://doi.org/10.2105/AJPH.86.5.668
Takano, T. (2002). Urban residential environments and senior citizens' longevity in megacity areas: the importance of walkable green spaces. *Journal of Epidemiology & Community Health*, *56*(12), 913–918. https://doi.org/10.1136/jech.56.12.913
Tan, J., Zheng, Y., Tang, X., Guo, C., Li, L., Song, G., Zhen, X., Yuan, D., Kalkstein, A. J., Li, F., & Chen, H. (2010). The urban heat island and its impact on heat waves and human health in Shanghai. *International Journal of Biometeorology*, *54*(1), 75–84. https://doi.org/10.1007/s00484-009-0256-x

Tang, J., & Long, Y. (2019). Measuring visual quality of street space and its temporal variation: Methodology and its application in the Hutong area in Beijing. *Landscape and Urban Planning*, *191*(July 2017), 103436. https://doi.org/10.1016/j.landurbplan.2018.09.015
Tannous, H. O., Major, M. D., & Furlan, R. (2021). Accessibility of green spaces in a metropolitan network using space syntax to objectively evaluate the spatial locations of parks and promenades in Doha, State of Qatar. *Urban Forestry & Urban Greening*, *58*, 126892. https://doi.org/10.1016/j.ufug.2020.126892
Tao, Z., Cheng, Y., & Liu, J. (2020). Hierarchical two-step floating catchment area (2SFCA) method: measuring the spatial accessibility to hierarchical healthcare facilities in Shenzhen, China. *International Journal for Equity in Health*, *19*(1), 164. https://doi.org/10.1186/s12939-020-01280-7
Tapiro, H., Oron-Gilad, T., & Parmet, Y. (2020). Pedestrian distraction: The effects of road environment complexity and age on pedestrian's visual attention and crossing behavior. *Journal of Safety Research*, *72*, 101–109. https://doi.org/10.1016/j.jsr.2019.12.003
The Community Guide. (2016). *Physical activity: built environment approaches combining transportation system interventions with land use and environmental design*. www.thecommunityguide.org/findings/physical-activity-built- environment-approaches
Thoma, M. V., Mewes, R., & Nater, U. M. (2018). Preliminary evidence. *Medicine*, *97*(8), e9851. https://doi.org/10.1097/MD.0000000000009851
Thornhill, I., Hill, M. J., Castro-Castellon, A., Gurung, H., Hobbs, S., Pineda-Vazquez, M., Gómez-Osorio, M. T., Hernández-Avilés, J. S., Novo, P., Mesa-Jurado, A., & Calderon-Contreras, R. (2022). Blue-space availability, environmental quality and amenity use across contrasting socioeconomic contexts. *Applied Geography*, *144*(November 2021), 102716. https://doi.org/10.1016/j.apgeog.2022.102716
Tian, D., Wang, J., Xia, C., Zhang, J., Zhou, J., Tian, Z., Zhao, J., Li, B., & Zhou, C. (2024). The relationship between green space accessibility by multiple travel modes and housing prices: A case study of Beijing. *Cities*, *145*(January 2023), 104694. https://doi.org/10.1016/j.cities.2023.104694
Troy, A., Nunery, A., & Grove, J. M. (2016). The relationship between residential yard management and neighbourhood crime: An analysis from Baltimore City and County. *Landscape and Urban Planning*, *147*, 78–87. https://doi.org/10.1016/j.landurbplan.2015.11.004
Tulchinsky, T. H., & Varavikova, E. A. (2023). *The new public health*. Elsevier. https://doi.org/10.1016/C2019-0-04675-4
Turner, A. (2007). From axial to road-centre lines: A new representation for space syntax and a new model of route choice for transport network analysis. *Environment and Planning B: Planning and Design*, *34*(3), 539–555. https://doi.org/10.1068/b32067
UK Government. (2009). *Marine and Coastal Access Act 2009*.
Ulrich, R. S. (1981). Natural versus urban scenes. *Environment and Behavior*, *13*(5), 523–556. https://doi.org/10.1177/0013916581135001
Ulrich, R. S. (1984). View through a window may influence recovery from surgery. *Science*, *224*(4647), 420–421. https://doi.org/10.1126/science.6143402
Ulrich, R. S., Simons, R. F., Losito, B. D., Fiorito, E., Miles, M. A., & Zelson, M. (1991). Stress recovery during exposure to natural and urban environments. *Journal of Environmental Psychology*, *11*(3), 201–230. https://doi.org/10.1016/S0272-4944(05)80184-7
UN General Assembly. (2015). *Transforming our world: The 2030 agenda for sustainable development*. United Nations.
United Nations. (2018). The World's Cities in 2018. In *World Urbanisation Prospects: The 2018 Revision*. https://www.un.org/en/development/desa/population/publications/pdf/urbanization/the_worlds_cities_in_2018_data_booklet.pdf
Vaeztavakoli, A., Lak, A., & Yigitcanlar, T. (2018). Blue and green spaces as therapeutic landscapes: Health effects of urban water canal areas of Isfahan. *Sustainability (Switzerland)*, *10*(11). https://doi.org/10.3390/su10114010
van den Berg, M., van Poppel, M., van Kamp, I., Andrusaityte, S., Balseviciene, B., Cirach, M., Danileviciute, A., Ellis, N., Hurst, G., Masterson, D., Smith, G., Triguero-Mas, M., Uzdanaviciute, I., Wit, P. de, Mechelen, W. van, Gidlow, C., Grazuleviciene, R., Nieuwenhuijsen, M. J., Kruize, H., & Maas, J. (2016). Visiting green space is associated with mental health and vitality: A cross-sectional study in four european cities. *Health & Place*, *38*, 8–15. https://doi.org/10.1016/j.healthplace.2016.01.003

van den Bogerd, N., Elliott, L. R., White, M. P., Mishra, H. S., Bell, S., Porter, M., Sydenham, Z., Garrett, J. K., & Fleming, L. E. (2021). Urban blue space renovation and local resident and visitor well-being: A case study from Plymouth, UK. *Landscape and Urban Planning*, *215*(December 2020), 104232. https://doi.org/10.1016/j.landurbplan.2021.104232

Van Hedger, S. C., Nusbaum, H. C., Clohisy, L., Jaeggi, S. M., Buschkuehl, M., & Berman, M. G. (2019). Of cricket chirps and car horns: The effect of nature sounds on cognitive performance. *Psychonomic Bulletin & Review*, *26*(2), 522–530. https://doi.org/10.3758/s13423-018-1539-1

Van Renterghem, T., Forssén, J., Attenborough, K., Jean, P., Defrance, J., Hornikx, M., & Kang, J. (2015). Using natural means to reduce surface transport noise during propagation outdoors. *Applied Acoustics*, *92*, 86–101. https://doi.org/10.1016/j.apacoust.2015.01.004

VanLandingham, M. (2014). On the hard and soft sciences in public health. *Public Health Reports*, *129*(2), 124–126. https://doi.org/10.1177/003335491412900204

VanLare, J. M., & Conway, P. H. (2012). Value-based purchasing — National programs to move from volume to value. *New England Journal of Medicine*, *367*(4), 292–295. https://doi.org/10.1056/NEJMp1204939

Vári, Á., Podschun, S. A., Erős, T., Hein, T., Pataki, B., Iojă, I.-C., Adamescu, C. M., Gerhardt, A., Gruber, T., Dedić, A., Ćirić, M., Gavrilović, B., & Báldi, A. (2022). Freshwater systems and ecosystem services: Challenges and chances for cross-fertilisation of disciplines. *Ambio*, *51*(1), 135–151. https://doi.org/10.1007/s13280-021-01556-4

Vassiljev, P., Bell, S., Balicka, J., & Amrita, U. A. A. (2020). Urban blue acupuncture: An experiment on preferences for design options using virtual models. *Sustainability*, *12*(24), 10656. https://doi.org/10.3390/su122410656

Vert, C., Carrasco-Turigas, G., Zijlema, W., Espinosa, A., Cano-Riu, L., Elliott, L. R., Litt, J., Nieuwenhuijsen, M. J., & Gascon, M. (2019). Impact of a riverside accessibility intervention on use, physical activity, and wellbeing: A mixed methods pre-post evaluation. *Landscape and Urban Planning*, *190*(July), 103611. https://doi.org/10.1016/j.landurbplan.2019.103611

Vert, C., Gascon, M., Ranzani, O., Márquez, S., Triguero-Mas, M., Carrasco-Turigas, G., Arjona, L., Koch, S., Llopis, M., Donaire-Gonzalez, D., Elliott, L. R., & Nieuwenhuijsen, M. (2020). Physical and mental health effects of repeated short walks in a blue space environment: A randomised crossover study. *Environmental Research*, *188*(June), 109812. https://doi.org/10.1016/j.envres.2020.109812

Vert, C., Nieuwenhuijsen, M., Gascon, M., Grellier, J., Fleming, L. E., White, M. P., & Rojas-Rueda, D. (2019). Health benefits of physical activity related to an urban riverside regeneration. *International Journal of Environmental Research and Public Health*, *16*(3), 462. https://doi.org/10.3390/ijerph16030462

Völker, S., Baumeister, H., Classen, T., Hornberg, C., & Kistemann, T. (2013). Evidence for the temperature-mitigating capacity of urban blue space - A health geographic perspective. *Erdkunde*, *67*(4), 355–371. https://doi.org/10.3112/erdkunde.2013.04.05

Völker, S., Heiler, A., Pollmann, T., Claßen, T., Hornberg, C., & Kistemann, T. (2018). Do perceived walking distance to and use of urban blue spaces affect self-reported physical and mental health? *Urban Forestry & Urban Greening*, *29*(February 2017), 1–9. https://doi.org/10.1016/j.ufug.2017.10.014

Völker, S., & Kistemann, T. (2011). The impact of blue space on human health and well-being – Salutogenetic health effects of inland surface waters: A review. *International Journal of Hygiene and Environmental Health*, *214*(6), 449–460. https://doi.org/10.1016/j.ijheh.2011.05.001

Völker, S., & Kistemann, T. (2013). “I’m always entirely happy when I’m here!” Urban blue enhancing human health and well-being in Cologne and Düsseldorf, Germany. *Social Science & Medicine*, *78*(1), 113–124. https://doi.org/10.1016/j.socscimed.2012.09.047

Völker, S., & Kistemann, T. (2015). Developing the urban blue: Comparative health responses to blue and green urban open spaces in Germany. *Health & Place*, *35*, 196–205. https://doi.org/10.1016/j.healthplace.2014.10.015

Wade, T. J., Pai, N., Eisenberg, J. N. S., & Colford, J. M. (2003). Do U.S. Environmental Protection Agency water quality guidelines for recreational waters prevent gastrointestinal illness? A systematic review and meta-analysis. *Environmental Health Perspectives*, *111*(8), 1102–1109. https://doi.org/10.1289/ehp.6241

Waltman, L., van Eck, N. J., & Noyons, E. C. M. (2010). A unified approach to mapping and clustering of bibliometric networks. *Journal of Informetrics*, *4*(4), 629–635. https://doi.org/10.1016/j.joi.2010.07.002

Wang, F. (2012). Measurement, optimisation, and impact of health care accessibility: A methodological review. *Annals of the Association of American Geographers*, *102*(5), 1104–1112. https://doi.org/10.1080/00045608.2012.657146
Wang, J. (2023). The digital presentation of human-oriented urban design. *Sustainable Cities and Society*, *97*(April), 104746. https://doi.org/10.1016/j.scs.2023.104746
Wang, S., Wang, M., & Liu, Y. (2021). Access to urban parks: Comparing spatial accessibility measures using three GIS-based approaches. *Computers, Environment and Urban Systems*, *90*, 101713. https://doi.org/10.1016/j.compenvurbsys.2021.101713
Wang, Y., Chau, C. K., Ng, W. Y., & Leung, T. M. (2016). A review on the effects of physical built environment attributes on enhancing walking and cycling activity levels within residential neighbourhoods. *Cities*, *50*, 1–15. https://doi.org/10.1016/j.cities.2015.08.004
Ward, M. D., & Gleditsch, K. S. (2019). *Spatial Regression Models*. SAGE Publications, Inc. https://doi.org/10.4135/9781071802588
Ward Thompson, C. (2011). Linking landscape and health: The recurring theme. *Landscape and Urban Planning*, *99*(3–4), 187–195. https://doi.org/10.1016/j.landurbplan.2010.10.006
Wheeler, B. W., White, M., Stahl-Timmins, W., & Depledge, M. H. (2012). Does living by the coast improve health and wellbeing? *Health & Place*, *18*(5), 1198–1201. https://doi.org/10.1016/j.healthplace.2012.06.015
White, M. P., Elliott, L. R., Gascon, M., Roberts, B., & Fleming, L. E. (2020). Blue space, health and well-being: A narrative overview and synthesis of potential benefits. *Environmental Research*, *191*(August), 110169. https://doi.org/10.1016/j.envres.2020.110169
White, M. P., Elliott, L. R., Grellier, J., Economou, T., Bell, S., Bratman, G. N., Cirach, M., Gascon, M., Lima, M. L., Lõhmus, M., Nieuwenhuijsen, M., Ojala, A., Roiko, A., Schultz, P. W., van den Bosch, M., & Fleming, L. E. (2021). Associations between green/blue spaces and mental health across 18 countries. *Scientific Reports*, *11*(1), 8903. https://doi.org/10.1038/s41598-021-87675-0
White, M. P., Wheeler, B. W., Herbert, S., Alcock, I., & Depledge, M. H. (2014). Coastal proximity and physical activity: Is the coast an under appreciated public health resource? *Preventive Medicine*, *69*, 135–140. https://doi.org/10.1016/j.ypmed.2014.09.016
White, M., Smith, A., Humphryes, K., Pahl, S., Snelling, D., & Depledge, M. (2010). Blue space: The importance of water for preference, affect, and restorativeness ratings of natural and built scenes. *Journal of Environmental Psychology*, *30*(4), 482–493. https://doi.org/10.1016/j.jenvp.2010.04.004
WHO. (2002). *Emerging issues in water and infectious disease*. World Health Organisation.
WHO. (2012). *Health 2020: a European policy framework supporting action across government and society for health and well-being*. World Health Organisation Regional Office for Europe.
WHO. (2013). *Global action plan for the prevention and control of noncommunicable diseases 2013-2020*. World Health Organisation.
WHO. (2017). *Urban green space interventions and health: A review of impacts and effectiveness*. World Health Organisation. http://www.euro.who.int/en/health-topics/environment-and-health/urban-health/publications/2017/urban-green-space-interventions-and-health-a-review-of-impacts-and-effectiveness.-full-report-2017
WHO. (2020). *Healthy cities effective approach to a rapidly changing world*. World Health Organisation. https://apps.who.int/iris/bitstream/handle/10665/331946/9789240004825-eng.pdf
WHO. (2021). *Green and blue spaces and mental health: New evidence and perspectives for action* (Issue July). World Health Organisation Regional Office for Europe.
Wilson, M. I., Robertson, L. D., Daly, M., & Walton, S. A. (1995). Effects of visual cues on assessment of water quality. *Journal of Environmental Psychology*, *15*(1), 53–63. https://doi.org/10.1016/0272-4944(95)90014-4
Wolff, M. (2021). Taking one step further – Advancing the measurement of green and blue area accessibility using spatial network analysis. *Ecological Indicators*, *126*, 107665. https://doi.org/10.1016/j.ecolind.2021.107665
Wong, D. W. S. (2004). The modifiable areal unit problem (MAUP). In *WorldMinds: Geographical Perspectives on 100 Problems* (Issue 1934, pp. 571–575). Springer Netherlands. https://doi.org/10.1007/978-1-4020-2352-1_93

Wong, N. H., Tan, C. L., Kolokotsa, D. D., & Takebayashi, H. (2021). Greenery as a mitigation and adaptation strategy to urban heat. *Nature Reviews Earth & Environment*, *2*(3), 166–181. https://doi.org/10.1038/s43017-020-00129-5

Wu, L., & Kim, S. K. (2021). Health outcomes of urban green space in China: Evidence from Beijing. *Sustainable Cities and Society*, *65*(November 2020), 102604. https://doi.org/10.1016/j.scs.2020.102604

Wyles, K. J., Pahl, S., Thomas, K., & Thompson, R. C. (2016). Factors that can undermine the psychological benefits of coastal environments. *Environment and Behavior*, *48*(9), 1095–1126. https://doi.org/10.1177/0013916515592177

Xiao, Y., Miao, S., Zhang, Y., Xie, B., & Wu, W. (2022). Exploring the associations between neighbourhood greenness and level of physical activity of older adults in shanghai. *Journal of Transport & Health*, *24*, 101312. https://doi.org/10.1016/j.jth.2021.101312

Xu, J., Ma, J., & Tao, S. (2024). Examining the nonlinear relationship between neighbourhood environment and residents' health. *Cities*, *152*(May), 105213. https://doi.org/10.1016/j.cities.2024.105213

Yamu, C., van Nes, A., & Garau, C. (2021). Bill Hillier's legacy: Space syntax—A synopsis of basic concepts, measures, and empirical application. *Sustainability*, *13*(6), 3394. https://doi.org/10.3390/su13063394

Yang, L., Yu, B., Liang, P., Tang, X., & Li, J. (2022). Crowdsourced data for physical activity-built environment research: Applying Strava data in Chengdu, China. *Frontiers in Public Health*, *10*. https://doi.org/10.3389/fpubh.2022.883177

Yang, Y., Wu, X., Zhou, P., Gou, Z., & Lu, Y. (2019). Towards a cycling-friendly city: An updated review of the associations between built environment and cycling behaviours (2007–2017). *Journal of Transport & Health*, *14*(July), 100613. https://doi.org/10.1016/j.jth.2019.100613

Yin, J., Ramanpong, J., Chang, J., Wu, C.-D., Chao, P.-H., & Yu, C.-P. (2023). Effects of blue space exposure in urban and natural environments on psychological and physiological responses: A within-subject experiment. *Urban Forestry & Urban Greening*, *87*(August), 128066. https://doi.org/10.1016/j.ufug.2023.128066

You, J., Lee, P. J., & Jeon, J. Y. (2010). Evaluating water sounds to improve the soundscape of urban areas affected by traffic noise. *Noise Control Engineering Journal*, *58*(5), 477. https://doi.org/10.3397/1.3484183

Yu, S., Yu, B., Song, W., Wu, B., Zhou, J., Huang, Y., Wu, J., Zhao, F., & Mao, W. (2016). View-based greenery: A three-dimensional assessment of city buildings' green visibility using Floor Green View Index. *Landscape and Urban Planning*, *152*, 13–26. https://doi.org/10.1016/j.landurbplan.2016.04.004

Zeisel, J. (1984). *Inquiry by design: Tools for environment-behaviour research*. Cambridge University Press.

Zhang, A., Song, L., & Zhang, F. (2022). Perception of pleasure in the urban running environment with street view images and running routes. *Journal of Geographical Sciences*, *32*(12), 2624–2640. https://doi.org/10.1007/s11442-022-2064-8

Zhang, D., Xu, J., Zhang, Y., Wang, J., He, S., & Zhou, X. (2020). Study on sustainable urbanisation literature based on Web of Science, scopus, and China national knowledge infrastructure: A scientometric analysis in CiteSpace. *Journal of Cleaner Production*, *264*, 121537. https://doi.org/10.1016/j.jclepro.2020.121537

Zhang, F., Zhou, B., Liu, L., Liu, Y., Fung, H. H., Lin, H., & Ratti, C. (2018). Measuring human perceptions of a large-scale urban region using machine learning. *Landscape and Urban Planning*, *180*(October 2017), 148–160. https://doi.org/10.1016/j.landurbplan.2018.08.020

Zhang, H., Nijhuis, S., & Newton, C. (2022). Freshwater blue space design and human health: A comprehensive research mapping based on scientometric analysis. *Environmental Impact Assessment Review*, *97*, 106859. https://doi.org/10.1016/j.eiar.2022.106859

Zhang, H., Nijhuis, S., & Newton, C. (2023a). Uncovering the visibility of blue spaces: Design-oriented methods for analysing water elements and maximising their potential. *Journal of Digital Landscape Architecture*, *2023*(8), 628–638. https://doi.org/10.14627/537740066

Zhang, H., Nijhuis, S., & Newton, C. (2023b). Advanced digital methods for analysing and optimising accessibility and visibility of water for designing sustainable healthy urban environments. *Sustainable Cities and Society*, *98*(June), 104804. https://doi.org/10.1016/j.scs.2023.104804

Zhang, H., Nijhuis, S., Newton, C., & Tao, Y. (2024). Healthy urban blue space design : Exploring the associations of blue space quality with recreational running and cycling using crowdsourced data. *Sustainable Cities and Society*, *117*(February), 105929. https://doi.org/10.1016/j.scs.2024.105929

TOC

Zhang, X., Lu, H., & Holt, J. B. (2011). Modelling spatial accessibility to parks: a national study. *International Journal of Health Geographics*, *10*(1), 31. https://doi.org/10.1186/1476-072X-10-31

Zhou, B., Zhao, H., Puig, X., Xiao, T., Fidler, S., Barriuso, A., & Torralba, A. (2019). Semantic understanding of scenes through the Ade20k dataset. *International Journal of Computer Vision*, *127*(3), 302–321. https://doi.org/10.1007/s11263-018-1140-0

Zhou, H., Gu, J., Liu, Y., & Wang, X. (2022). The impact of the “skeleton” and “skin” for the streetscape on the walking behaviour in 3D vertical cities. *Landscape and Urban Planning*, *227*(November 2021), 104543. https://doi.org/10.1016/j.landurbplan.2022.104543

Zhou, H., He, S., Cai, Y., Wang, M., & Su, S. (2019). Social inequalities in neighbourhood visual walkability: Using street view imagery and deep learning technologies to facilitate healthy city planning. *Sustainable Cities and Society*, *50*(129), 101605. https://doi.org/10.1016/j.scs.2019.101605

Curriculum Vitae

Haoxiang Zhang (张皓翔)

Haoxiang Zhang was born in Taiyuan, China, in 1992. He commenced his academic journey in Landscape Architecture at Southeast University in 2011, earning a Bachelor of Engineering degree in 2017. Subsequently, Haoxiang pursued a Master's degree in Architecture at the same institution, engaging in extensive research and practical work in urban design under the supervision of Professor Jianguo Wang. He graduated with distinction in 2020 after completing his master's thesis titled "Research on the Design of Changzhou Cultural Palace Square Based on the Perspective of Vitality Regeneration."

In 2021, Haoxiang was awarded a joint scholarship from the Chinese Scholarship Council (CSC) and the Dutch Organisation for Internationalisation in Education (Nuffic), enabling him to commence his PhD studies in the Department of Urbanism at the Faculty of Architecture and the Built Environment, Delft University of Technology, The Netherlands. His research primarily focuses on health-oriented urban design and landscape planning, the application of digital spatial analysis methods, and the theory and practice of design research. He presented his research findings at several international conferences, including the International Federation of Landscape Architecture (IFLA) Congress 2024, the Digital Landscape Architecture Conference (DLA) 2023, the Association of European Schools of Planning (AESOP) Annual Congress 2022, and the Annual National Planning Conference of China 2019. His scholarly contributions have been published in Sustainable Cities and Society, Environment Impact Assessment Review, Journal of Digital Landscape Architecture, Landscape Architecture Journal, and so on.

Publications

Peer-reviewed Journal Articles

Zhang, H., Nijhuis, S., Newton, C., & Tao Y. (2024). Designing healthy urban blue spaces: Exploring the association between spatial quality of blue space and recreational physical activity using crowdsourced data. *Sustainable Cities and Society*, 117(February), 105929.

Zhang, H., Nijhuis, S., & Newton, C. (2024). Healthy Blue Space Design: A Methodological Framework for Translating the Health Benefits of Blue Space Exposure and Perception into Design Practices. *Landscape Architecture Journal*, *2024*, *31*(7), 39-47.

Zhang, H., Nijhuis, S., & Newton, C. (2023). Advanced digital methods for analysing and optimising accessibility and visibility of water for designing sustainable healthy urban environments. *Sustainable Cities and Society*, *98*(June), 104804.

Zhang, H., Nijhuis, S., & Newton, C. (2023). Uncovering the Visibility of Blue Spaces: Design-oriented Methods for Analysing Water Elements and Maximizing Their Potential. *Journal of Digital Landscape Architecture*, *2023*(8), 628–638.

Zhang, H., Nijhuis, S., & Newton, C. (2022). Freshwater blue space design and human health: A comprehensive research mapping based on scientometric analysis. *Environmental Impact Assessment Review*, *97*, 106859.

Lu, L., & Zhang, H. (2024). Cultivating Water-Human Intimacy within the Built Environment: Insights from the Master of the Nets Garden. *Blue Papers*, *3*(2), 34-51.

Bao, Z., Zhang, T., Nijhuis, S., & Zhang, H. (2024). River Style Framework: A Hydro-morphology Assessment Framework for Sustainable Riverscape Restoration and Management. *Chinese Landscape Architecture*, *2024*, *40*(3), 48-54.

Zhang, H. (2020). Research on the Landscape Resource Quantitative Evaluation Based on the Concept of “Mapping”: Illustrated by the Example of Nanjing Gulin Park. *Huazhong Architecture*, *2020*, *5*, 77-81.

Submitted Papers

Zhang, H., Nijhuis, S., Newton, C., & Shan, L. (Submitted to a peer-reviewed journal, under second round review). Running in Rotterdam's Blue Spaces: Age Group Preferences and the Impact of Visual Perceptions.

Conference Presentation

Zhang, H. (September, 2024). Healthy Urban Blue: Exploring the potential of volunteered geographic information data and street view images in creating exercise-friendly urban environment. In *IFLA 2024*. Istanbul, Turkey.

Zhang, H. (May, 2023). Uncovering the Visibility of Blue Spaces: Design-oriented Methods for Analysing Water Elements and Maximizing Their Potential. In *DLA 2023*. Dessau, Germany.

Zhang, H. (September, 2022). Healthy Urban Blue: A methodological framework for linking human health and blue space design. In *AESOP 2022*. Tartu, Estonia.

24#06

Designing Healthy Blue Spaces

Principles, Patterns, and Methods for Freshwater Blue Space Design in Urban Environments

Haoxiang Zhang

This thesis investigates the practical connection between health-promoting evidence and the spatial design of blue spaces. This endeavour aims to develop instrumental resources that facilitate the integration of the health benefits of natural environments into actionable strategies, thereby augmenting the development of design research and enhancing understanding of the nature-health nexus. The research methodically examines three interrelated aspects: understanding the academic contexts and methodological preparation from the design perspective, development of qualitative and quantitative design knowledge for fulfilling health benefits of blue spaces, and applications and reflections on proposed knowledge through design workshops and interviews. Initially, the thesis outlines the relationship between blue space and health from a design perspective, identifying a significant, unexplored gap. It then proposes a methodological framework to translate health-promoting evidence of blue spaces into design knowledge for practices. Subsequently, this thesis employs interdisciplinary techniques, integrating both qualitative and quantitative approaches, to generate varied types of design knowledge, including distilling worldwide precedent cases, summarising diverse geospatial and visualisation tools, and translating site-based evidence using spatiotemporal crowdsourcing data. The effectiveness and usability of the proposed knowledge are evaluated through design workshops, complemented by expert interviews across various fields, providing insights that reflect on the research outcomes and suggest future directions. Overall, by focusing on the interactive relationship between research and design, the principal contribution of this research lies in its attempt to translate theoretical evidence from public health into practical design interventions, exploring the potential of interdisciplinary tools and methods in facilitating this process.

A+BE | Architecture and the Built Environment | TU Delft BK