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Cyclists' perception of streetscape and its influence on route choice: A pilot study with a mixed-methods approach

Roberto Nacxit Ramirez Juarez [a], Anna Beatriz Grigolon [b,*], Ana Mafalda Madureira [a]

[a] *Faculty of Geo-Information & Earth Observation, University of Twente, the Netherlands*
[b] *Faculty of Engineering Technology, Department of Civil Engineering, University of Twente, the Netherlands*

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ABSTRACT

To encourage behavioural changes that reduce car use, understanding travel behaviour and interventions in infrastructure are necessary. Understanding the route choices of cyclists and their motivation based on their preferences regarding their trip attributes is essential to improve cycling infrastructure and encourage active travel modes such as cycling. This research aims to explore the influence of streetscape design features (SDFs) on cyclists' route choices by developing a mixed-method approach to collect objective and subjective data from 22 volunteers. We used a survey (Maptionnaire) with a virtual reality (VR) and eye-tracking experiment to simulate a bicycle trip in Enschede, The Netherlands. Results showed that despite differences between usual and ideal routes regarding SDFs (such as the presence of vegetation, water bodies, and road intersections), factors such as infrastructure provision and quality have a more significant impact when choosing a route. The novelty of the proposed methodology lies in combining data from the different methods to improve understanding regarding the influence of SDFs in cyclists' route choices and raise awareness among the participants about the influence of SDFs on their route choices. These results may encourage future studies to develop and implement alternative mixed-methods approaches to increase understanding of cyclists' travel behaviour. From a practitioner's perspective, implementing such mixed-method for data collection may increase the efficiency of the process to aid in the development of contextual data-driven interventions that encourage the use of bicycles.

1. Introduction

Many studies have explored human behaviour in the past to understand the influence of the built environment on travel behaviour from socio-economic, spatial and personal perspectives (i.e. Bohte et al., 2009; van Acker et al., 2010). Other studies also explored travel behaviour concerning travel modes (i.e. Klöckner & Blöbaum, 2010; Klöckner & Friedrichsmeier, 2011) and route choices (i.e. Hardinghaus & Papantoniou, 2020; Segadilha et al., 2014). In the case of cyclists' route choice behaviour, interaction with the environment and its attributes such as dedicated bike lanes, number of crossings, and presence of greenery has shown to be desirable and influential when choosing a route to move from one point to another (Hardinghaus & Papantoniou, 2020; Li et al., 2017). Therefore, improving the infrastructure with targeted interventions and encouraging bike use requires identifying the elements of the

* Corresponding author.
E-mail addresses: r.n.ramirezjuarez@utwente.nl (R.N. Ramirez Juarez), a.b.grigolon@utwente.nl (A.B. Grigolon), m.madureira@utwente.nl (A.M. Madureira).

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built environment (BE) that influence route choice as part of the cycling experience.

Previous research has explored the relationship between travel behaviour and the BE. For instance, Cervero & Kockelman (1997) identified the "3 D's" of the BE that encourage active transportation: Density, Diversity, and Design. Also, current research on the influence of BE on cyclists' travel behaviour has continued exploring these variables (Liu et al., 2021; Ospina et al., 2020). However, there is a tendency to focus on the density and diversity dimensions while the design is relatively less discussed (Eom & Cho, 2015; Wang & Zhou, 2017). The design dimension involves features that reward pedestrians, cyclists or transit riders with the intention of 'levelling the playing field' with car drivers (Cervero & Kockelman, 1997). In the case of cycling, the provision of aesthetical amenities has been found to be a top motivator for the enjoyment of the cycling experience among users (Winters et al., 2010). In addition, aesthetical attributes such as signalised intersections and pavement quality influence the route choice when cycling and are also related to convenience and safety factors (Chen et al., 2017). Studies that focus on the relationship between travel behaviour and the 3 D's analyse the macro-level of the built environment (i.e. neighbourhood, traffic analysis zone, or census block level). This research focuses on the micro-level attributes of the BE to explore their influence on individual travel behaviour. The attention to the micro-scale attributes is in line with the findings of Ito & Biljecki (2021) that suggest that street-level indicators (i.e. greenery or building design) may have a stronger correlation with bikeability in comparison with macro-level indicators (i.e. density or elevation). Also studies such as Harvey et al. (2015), Yang et al. (2021), and Zhou et al. (2022) explore the influence of the micro-level attributes of the BE on walking behaviour and safety. Even though these studies focus on walking behaviour, some of the attributes such as greenery and diversity of facades can be also related to cycling behaviour.

To increase understanding of the factors that cyclists consider to choose a route, the differences between the usual and ideal routes should be explored. Usual routes are often the shortest path, whereas the ideal routes are not constrained by time or distance, and thus, can be significantly longer and more likely to be influenced by other factors such as aesthetic amenities (Winters et al., 2010) together with well researched factors such as street connectivity and the presence of cycling paths and facilities (Yang et al., 2019). In previous studies (i.e. Ehrgott et al., 2012; Koh & Wong, 2013; Lu et al., 2018), safety and aesthetic conditions such as road intersections, quality of pavement, presence of trees and, building design have been considered influential factors for cyclists' route choices.

Psychological factors such as the individual's perception have also greatly influenced cyclists' travel choices (Willis et al., 2015). Perception can be defined as "the way sensory information is organised, interpreted, and consciously experienced" (Spielman et al., 2020, p.157). Regarding the perception of the BE, objective attributes are often considered more reliable than the perceived, more subjective ones (Y. Yang et al., 2019). In the case of cycling behaviour, the influence of both objective and perceived BE has been studied. Objective attributes such as street design, traffic speeds and volumes, the density of businesses, etc. have strongly influenced travel behaviour as they directly influence the perceptions of the BE (Ma et al., 2014). In this case, data about objective attributes can be easily gathered by field audits however, subjective data (perceptions) is often more complex.

The difficulty in capturing perception lies in the interpretation process of reality. This interpretation of reality can be analysed from two main perception approaches, Top-Down and Bottom-Up (Spielman et al., 2020). A Top-Down approach refers to the direct influence of the physical environment in perception; in other words, how design features such as trees, pavement, facades, etc. and other sensory information like smell or sound influence the perception of the environment. A Bottom-Up approach refers to interpreting the receiving information based on prior knowledge, experiences and expectations; this means that, in a Bottom-Up approach, the reality is processed based on individual preferences and backgrounds. Differentiation between these two approaches would allow the development of tools to measure specific types of perception; for example, surveys may help to understand perception from the Bottom-Up approach, while a ride-along interview is a Top-Down approach.

This study aims to contribute to the understanding of the influence of streetscape design features (SDFs) on cyclists' route choices. For this, we develop a mixed-method approach that combines bottom-up and top-down approaches to allow collecting data on cyclists' perception of SDFs and its influence on their route choice behaviour. We explore how information about cyclists' perception (from both top-down and bottom-up approaches) of streetscape design features can be collected and represented for a given context. We then assess the added value of the proposed methodology from a user perspective and discuss the extent to which the proposed mixed-method approach helps to increase understanding of the impact of SDFs on cyclists' route choices. Studies that consider both top-down and bottom-up approaches to investigate perceptions are common in the fields of neuroscience (e.g. McMains & Kastner, 2011), psychology (e.g. Gençer & Yıldırım, 2021; Riener, 2019) and, cartography (e.g. Kiefer et al., 2017); however, up to our knowledge, there are no studies on the travel behaviour field that combine both approaches as part of their methodology. Hence the novelty of the implemented methodology for this study.

The proposed methodology was applied to the city of Enschede, a medium-sized municipality with about 160 thousand inhabitants (Central Bureau of Statistics, 2021) located in the Overijssel region in the east of The Netherlands. In 2020, the city ranked among the top-five cycling cities in The Netherlands (Fietsersbond, 2020). Since 2012, the municipality has been working on improving bike-commuting movements, where the main focus is providing safety for cyclists and improving the connectivity of the bicycle infrastructure network (Enschede, 2012). However, to the best of our knowledge, interventions towards improving the aesthetics around the infrastructure to improve the riding experience have not been targeted specifically and according to cyclists' preferences. The insights gained from the results of this study can help inform current municipal strategies to encourage cycling behaviour by emphasising the design elements of a built environment that improve the cycling experience.

2. Literature Review: SDFs influencing cyclists' route choice and data collection approaches

Cycling is influenced by the provision of infrastructure (such as bike lanes, crossings, etc.) in combination with the perception of SDFs of the routes (Desjardins et al., 2021). In this paper, a systematic literature review (section 3.1) was developed to identify the

SDFs that, according to existing literature, influence cyclists' route choice behaviour, followed by a review of existing methods to identify, measure and analyse the influence of SDFs on cyclists' route choice behaviour.

Recent studies have focused on which SDFs (such as trees, illumination or window apparels) affect travel choices for non-motorized means of transport e.g. Cole-Hunter et al., 2015; Desjardins et al., 2021; Sun et al., 2017; Verhoeven et al., 2018. Also, studies focusing specifically on route choice of cyclists and the relationship with the built environment remark the importance of the design dimension (aesthetics); an example is the research of Desjardins et al. (2021), where they found that cycling is influenced in a large part by the quality, design and connectivity aspects of the infrastructure as participants discussed the perceptions of street-level features more than land use or urban form. However, the study did not address what are the specific street-level features that impact the route decision.

To better understand the relationship between SDFs and cycling route choice behaviour, adding a spatial component to the analysis may improve understanding of this relationship. For example, previous studies have used bottom-up approaches such as datasets from GPS-tracking apps such as STRAVA (McArthur & Hong, 2019) or Hamilton Bike Share (Scott et al., 2021). Via these data collection tools, participants first use the GPS app during the cycling activity to record their routes. These GPS routes are combined with secondary data to find the relationships between the built environment and the recorded routes.

GPS-tracking apps (i.e. STRAVA) allow researchers to obtain large amounts of data about cycling trips. However, the retrieved data from these apps is potentially biased regarding the sample's representativeness as users of such apps are often cyclists that ride more for leisure purposes (Garber et al., 2019). These biases in the data collection could be mitigated by combining multiple datasets to improve the sample's representativeness. One example of this combination of datasets can be found in the work of Alattar et al. (2021), where the compensation for missing data from STRAVA was the implementation of a Public Participation Geographic Information System (PPGIS) with local STRAVA non-users.

One example of a PPGIS is the web-based tool Maptionnaire. As a PPGIS, this tool allows researchers to reach out to a broad public to collect place-specific data with a customised survey that is designed to fit the specific purposes of the research in a given context and allows participants not to only contribute by digitising their routes but also to mark and comment on location-based attributes (Maptionnaire, 2020). The possibility of using a tailor-made survey design allows us to compensate for representation biases in the dataset and consider other factors such as gender, age or trip purpose in the case of cyclists' route choice behaviour.

The development of new technologies generates alternatives to explore an individual's perception. As an example of a top-down approach, Virtual Reality (VR) has been used to replace physical streetscape audits reducing the time taken to complete a visual audit compared to a physical audit. In the case of travel behaviour, VR has been used in studies to evaluate pedestrians' behaviour (Bhagavathula et al., 2018; Maghelal et al., 2011) or to evaluate cyclists' perception of safety (Nazemi et al., 2021). These studies use different set-ups such as single or multiple screens, projectors or headsets to simulate the virtual environment.

For example, Nazemi et al. (2021) used a stationary bike and a 360-degree VR headset to explore five cycling scenarios with different bike path characteristics. Even if they do not use the same set-up for the VR experience, these studies highlight the advantages of using VR as a reliable tool to capture perception in a safe and controlled environment. This method is found to compensate for contextual physical differences such as time of the day, weather conditions, road and traffic characteristics, etc. that may introduce variances in the data.

3. Methods

In this paper, we propose a mixed-method approach that will allow collecting data on cyclists' perceptions of SDFs and their influence on route choice. This approach is guided by the questions, "What are the SDFs that affect route choice of cyclists according to literature?" and "How can information about cyclists' perception (from both top-down and bottom-up approaches) of SDFs be collected and represented for a given context?".

3.1. Systematic literature review

First, to identify the SDFs that influence cyclists' route choice and the latest data collection approaches, we conducted a systematic literature review based on peer-reviewed publications from the last 10 years (2011–2021). The key concepts of this research (Streetscape, Cycling, Route choice) were searched across three different databases: Scopus, Web of Science and Science Direct. From this criteria, two search queries were created: the 'full' version, which uses Boolean operators and wildcards, and the 'refined' version,

Table 1
Overview of search queries and log used in the systematic literature review.

Search queries		
Complete	("Aesthetic*" **OR** "Street design" **OR** "Streetscap*") **AND** ("Cycl*" **OR** "Non-motor*" **OR** "Active transport*") **AND** ("Route choice*" **OR** "Travel behav*" **OR** "Path choice*")	
Refined	("Built environment" **OR** "Streetscape") **AND** ("Cycling") **AND** ("Route choice" **OR** "Path choice")	
Search log		
Database	**Query type**	**# Results**
Scopus	Full	528
Web of Science	Full	38
Science Direct	Refined	366

which does not incorporates wildcards as some databases do not support such elements or length as part of the query. An overview of the used search queries and search logs can be found in Table 1. The search queries provided a total of 932 results where, after scanning the methodology and results sections, 57 articles were selected for further analysis.

The resulting 57 articles were studies that included a list of SDFs and their influence on cycling behaviour as part of their results and a detailed explanation of the methods used for data collection. After going through the results of the chosen studies, the SDFs that were identified to be of medium or high influence on cycling route choices across most of the articles were listed. To allow simplification of the SDFs influencing cyclists' route choices and to improve the data collection process, three clusters related to the cycling experience were created. A list of the clusters and their respective elements is shown in Table 2.

3.2. Bottom-up approach: Survey

A survey instrument was developed to retrieve perception data from a bottom-up approach. This survey was designed to explore the differences between the participants' usual and ideal commuting routes with an added spatial element. Exploring the differences between the usual and the ideal routes was considered significant as the type of travel plays a role in perception as cycling for transport or recreation is associated with different environmental attributes (Heesch et al., 2015). Given these characteristics, the Maptionnaire software was considered a good fit as it combines survey questions with an interactive map.

The survey was divided into six sections: screening, digitising usual and ideal routes, features of the usual and ideal commuting routes, attitudes towards cycling, and demographics. The total survey length was 20 questions which took about 20 to 25 min to answer. A summary of the sections and respective questions is shown in Table 3.

The screening section aims to identify the frequency and degree of familiarity that participants have with cycling. The commuting and ideal route elicitation sections reveal the perception and pattern discrepancies between both types of routes. During the digitisation of these sections, participants were asked to add observations on specific sections they liked or disliked, which allowed the collection of additional information regarding the motivation to choose a specific route to reach the destination.

The section related to cycling attitudes was based on the cyclist typologies focused on understanding better cycling behaviour proposed by Geller, (2006). Geller's categories are determined by a person's comfort while riding a bike. The 'fearless' cyclists will ride regardless of roadway conditions and take identity from riding a bike, the 'confident' ones are comfortable riding on shared roads with cars but prefer to operate with their lane, the 'concerned' cyclists are the ones that like to ride but are afraid to do so regularly because of the bike infrastructure, and the 'no way/no how' are the ones that do not ride a bike for reasons of topography, inabilities or lack of motivation or interest in the activity.

According to Dill & McNeil (2013), there are significant differences in perception of the physical environment among different types of cyclists related to safety. To complement the factors that may influence perception, the section about demographics considers questions related to age group and education level.

3.3. Top-down approach: VR & eye-tracking

A VR experiment was developed to complement the survey to assess the perception of the aesthetical elements during cycling from a top-down approach. This experiment combined VR with eye-tracking technology to simulate a bike ride. Combining the results from the experiment and the survey allowed a comparison between stated preferences from a bottom-up approach against their reactions to a real-time cycling experience from a top-down approach.

The simulated bike ride was developed using a Tobii VIVE Pro Eye headset coupled with the TobiiProlab software (Tobii Pro AB, 2014) and a 360-degree camera (INSTA ONE X2) mounted on a helmet to make the recordings of the bike rides. Exposing the participants to pre-recorded routes was considered an alternative to avoid external factors such as variability in weather, traffic volumes, and speed conditions that may affect the comparison with eye-tracking.

Table 2
Clusters of design elements from the chosen literature that influence cyclists' route choices.

Cluster (Looking to…)	Streetscape Design Feature
Front	Type of cycling lane
	Stop lights
	Amount of intersections
Foreground	Pavement quality
	Surface material
	Bicycle lane width
Context	Parking availability for bikes along the way
	Diversity in building's facades
	Diversity of land use
	Presence of street-level windows
	Presence of tall buildings
	Presence of trees
	Presence of grass/vegetation
	Presence of landmarks
	Presence of water bodies

Table 3
Summary of survey questions.

Section	Question	Answer option/action
Screening	How often do you commute by bicycle per week?	Never 1 2 to 3 More than 4
	How long have you been living in Enschede?	Less than a year 1 year Between 2 and 3 years More than 4 years
Commuting	On the map, draw your most common route for commuting to ITC by bike.	Drawing polyline
Ideal	Imagine you do not have any time or distance constraints. Draw your ideal route for commuting to ITC by bike	Drawing polyline
Commuting/ Ideal	From your route, indicate which sections you like the most (and why).	Drawing line
	From your route, indicate which sections you dislike the most (and why).	Drawing line
	Add a marker of the things you like about this route.	Adding point
	Add a marker of the things you dislike about this route.	Adding point
	From the following list, which design attributes do you consider important for choosing this route?	List of SDFs (see Table 2)
	From the following factors, which ones do you consider for choosing this route?	Shortest route Fastest route Low motorised traffic volume High pedestrian traffic volumeSlope (inclination) Traffic safety
Attributes	In terms of safety, to which of the following typologies do you relate your cycling behaviour?	Very comfortable even without bike lanes Somewhat comfortable while in bike lanes Not very comfortable while on bike lanes Very uncomfortable even in bike lanes
Demographics	What is your age?	Open question
	Which of these categories applies to you?	I am working I am studying I am working & studying

The simulations were based on four scenarios retrieved from the liked and disliked sections indicated by participants during the survey. The different scenarios are related to the bike ride experience and the aesthetical elements present in each of these segments that made most participants rate these sections as Good, Bad, Scenic or Average regarding their preferences during their cycling experiences. These section categories are assigned to every road segment based on existing aesthetical elements such as monumental buildings, picturesque nature, specific architectonical modern design or a clear horizon without obstructions. Even though rating of sections as good, bad, scenic or average can be highly subjective, for the evaluation of this attribute volunteers were encouraged to base their grading on the aesthetical factors neglecting personal preferences or particular feelings during their ride regarding the infrastructure itself (even surfaces or lane wideness).

In this case, the Good scenario runs through the city centre, which provides access for pedestrian and cycling traffic and has several storefronts on both sides of the path and landmarks (such as the main church) throughout the route. The Bad scenario follows a route that has a shared street with cars with a couple of street crossings, stop lights, and a combination of residential and business buildings on the sides of the road. The Scenic simulation runs through a park area with medium and tall trees on both sides on a semi-paved (gravel) path for pedestrians and cyclists. The Average scenario is a route that follows a long, straight line on a main street with an independent bike lane with the presence of greenery, residential buildings and supermarkets, and stop lights. Snapshots of these scenarios are presented in Fig. 1.

By having scenarios that differ in aesthetical quality, a comparison between their responses and their eye movements during the same sections was possible. This comparison helped to explore how the behaviour of participants changes between their stated preferences and their reaction to the same sections of their routes. Four Areas of Interest (AoI) were established to allow comparison between participants' eye movements. The AoIs were based on clusters of design elements that are influential for cyclists' route choices based on the results from the literature review (Table 2). These clusters of design elements can be translated into the simulation as AoI within a 190-degree field of view, as looking behind was not considered meaningful for the experiment. Fig. 2 exemplifies the AoI and the considered field of view used for measurements.

3.4. Added value of the mixed-methods approach

The assessment of data collection tools involving public participation in terms of their added value and usability is complex, outside the quality of the retrieved information. Pelzer et al, (2014) developed a framework to evaluate tools that involve public participation at the individual, group and outcome levels. The individual level focuses on the learning effects for the participants involved; the group

Fig. 1. Snapshots of different scenarios that were used for the experiment.

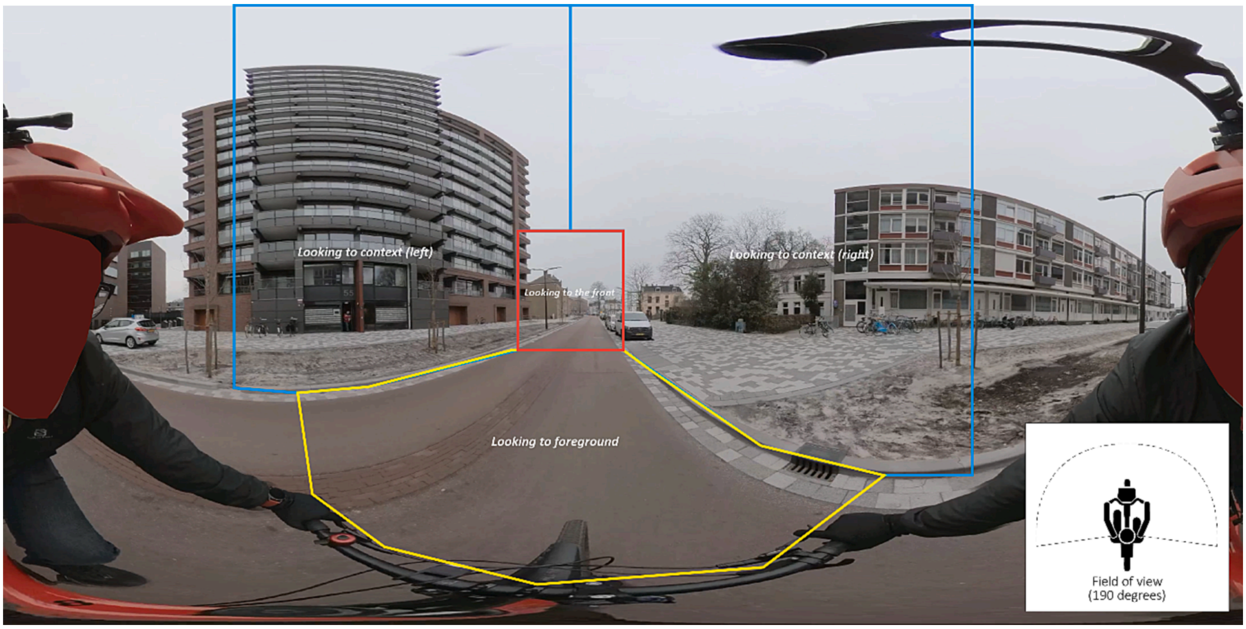

Fig. 2. Virtual Reality environment with AOIs and field of view.

level involves the exchange of information, collaboration and efficiency of the tool, and the outcome level considers the extent to which the tool influences the decision resulting from a participatory planning process.

In the case of tools intended for data collection, evaluating certain variables from the individual, group and outcome levels may provide insight into the added value of the tool, allowing the identification of potential uses and limitations of such tool for decision-making processes. An overview of the evaluation of participatory tools based on Pelzer et al., (2014) framework is illustrated in Fig. 3.

4. Data collection

Participants were recruited to test the implementation of this mixed-method approach to increase understanding of the influence of SDFs on cyclists' route choices. These participants were chosen based on five criteria: familiarity, common destination, demographics, language, and physical conditions. Familiarity relates to participants that are familiar with the activity of commuting by bicycle and that are used to the local context. Familiarity with the context allows participants to focus more on the experiences and perceptions of the scenery while cycling (Desjardins et al., 2021). A common destination among participants was considered to reveal the differences between the usual and ideal route. The common destination was the Faculty of Geo-Information Science and Earth Information (ITC) from the University of Twente (Enschede, The Netherlands) located within the study area in a relatively central location.

To reach out to participants, the institutional e-mail and WhatsApp social network among ITC staff and students were used for two weeks, resulting in a total of 22 respondents for the study. As the available time for research in a simulator is usually restricted, the number of participants involving a simulator experiment is rather limited (Kircher, 2007). Similar studies involving eye-tracking technology (eg. Giannopoulos et al., 2015; Popelka & Dolezălová, 2015; Schwarzkopf et al., 2016) contemplate sample sizes below 40 participants therefore, the sample size was considered enough to reveal a secure variety of information throughout the study area without saturating the dataset due to the size of the study area and the common destination. Also, due to the availability of a single VR headset and sanitary regulations (i.e. scheduling appointments to use the lab and no more than two people in the room), a large quantity of subjects could not be supported. Finally, to ensure safety, as the experiment phase involved participants using VR technology, people who suffered from motion sickness were screened out.

4.1. Evaluation of added value (post-survey)

We were interested in understanding to what extent the proposed mixed-method approach helps researchers to increase understanding about the impact of SDFs on cyclists' route choices. All participants were requested to fill out a post-study questionnaire to support the identification of the added value of the implemented methods from a user perspective. However, of all participants, only 10 out of 22 agreed to fill out the questionnaire. This questionnaire aimed to gain insights about learning from the experience and the usability of the implemented tools. The survey used a Likert scale (1 to 5) to allow comparison between tools. A summary of the survey is presented in Table 4, and the same questions were asked for both the survey and the VR experiment.

The section on Learning is intended to uncover the degree of reflection and awareness that participants gained after participating in the study and how the experience may have influenced their route choices or what they focus their attention on while cycling. The Usability section's questions are intended to assess the variables regarding using these tools in a public participation process. The questions are based on Pelzer et al., (2016) usability variables to evaluate planning support systems: transparency of information, communicative value, user-friendliness, level of detail, and integrality (Table 5). These variables were chosen as they may give insight into the possible flaws in the survey design and the experiment.

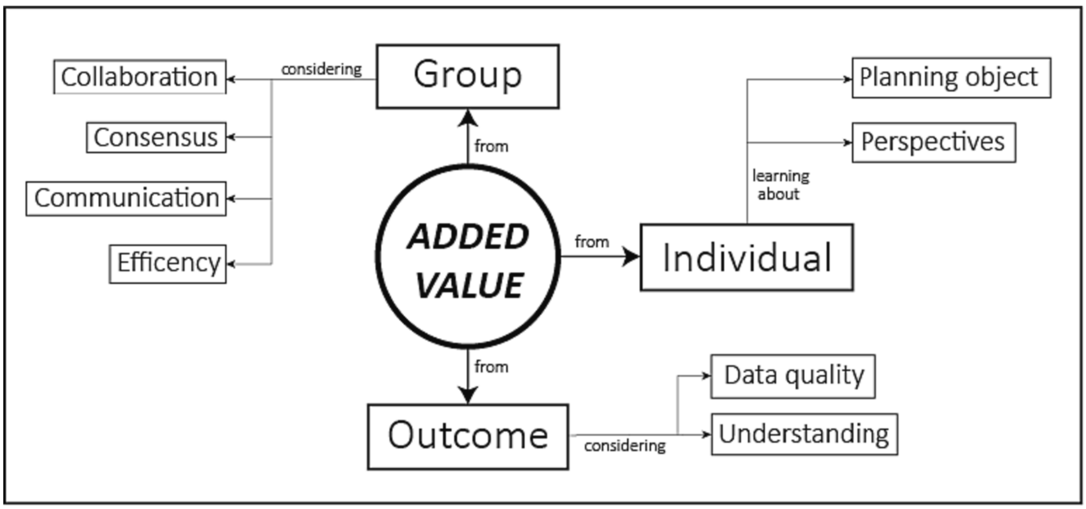

Fig. 3. Illustration about the added value of tools involving public participation based on the framework developed by Pelzer et al, (2014).

Table 4
Learning and usability survey for assessment of the added value of tools.

Section	Question
Learning	My attention to my surroundings increased when cycling.I think more about the reasons for choosing my commuting route.My preferences and criteria to choose my commuting route have changed.
Usability	The information and variables presented (definitions/video clips) were understandable to me.The visual (video/pictures/icons) and spatial (maps/landmarks) information were accordingly represented. I was able to use the tool without any inconvenience. The level of detail of the tool allowed me to provide a real answer to the questions.The tool allowed me to share my opinions about what I find interesting (attention) about a route when cycling.

5. Results

5.1. Maptionnaire survey

Regarding the individual characteristics of the collected responses from the 22 participants, the variability among the subjects' backgrounds was considered a positive influence as the sample would be able to represent perceptions from different ages and cultural backgrounds. Participants included staff and ITC faculty students with different ages and cultural backgrounds. However, due to the characteristics of the destination environment (a Higher Education institution) most participants had at least a bachelor's degree.

Half of the participants in the survey were students, and the rest were a mix of staff members and staff that is also studying (PhD candidates). From the sample, 14 people reported commuting by bike to work at least four times a week. This tendency suggests that participants strongly prefer using the bicycle as a transport mode for commuting. Also, there was a relationship between the time participants have been living in the city and the number of times that they commute by bike where more than half of the participants that were living for a year in the city (5 out of 9), used the bike more than four times a week, and 5 out of 6 people that has been living in the city for more than 4 years uses the bike with the same frequency. However, the sample size, context and recruitment strategy strongly affected the relationship between time spent living in the city and the cycling frequency.

The Maptionnaire survey also retrieved participants' perceptions of streetscape features and their influence on usual and ideal commuting routes. The survey provided insights from a bottom-up approach about cycling behaviour, perception of SDFs and stated preferences along the routes based on participants' previous experiences. Having the routes reported in a map allowed the selection of the four scenarios for the VR experiment making a comparison of perceptions from a top-down approach possible.

Differences regarding the streetscape design elements between the usual and the ideal commuting route were analysed, as shown in Table 6. Stated preferences for both routes such as pavement quality, adequate surface material and cycling lane width influencing route choices are in line with the findings of other authors (Cole-Hunter et al., 2015; Desjardins et al., 2021; Verhoeven et al., 2018) that suggest that even though aesthetical elements have an impact on the enjoyability of the ride, the provision of infrastructure and its quality are preferred when cyclists choose a route.

The main differences between the usual and the ideal route (Table 6) were found regarding the presence of road intersections, vegetation or water bodies, and avoidance of stop lights. Regarding preferences regarding 'stop lights avoidance' and 'least amount of road intersections', the results suggest that participants tend to be more time-efficient when choosing their usual route. This tendency is also supported by the stated preference in the survey, where 17 participants considered the 'fastest route' factor on their usual commuting route, against three respondents considering the 'fastest route' factor on their ideal route.

Regarding the preferences for aesthetical features, participants reported a higher preference for trees and vegetation in their ideal route than their usual route. Also, the preference for the diversity of land use was more significant in the ideal routes from participants. Results suggest that participants prioritise aesthetical factors when the time or distance constraints are not present. This result aligns with Winters et al., (2010) who found aesthetical amenities to be a top motivator for enjoying the cycling experience. However, regarding the degree of influence these elements may have when choosing a route, avoidance of stop lights and pavement quality may have the most significant impact. This influence is supported by the findings of Lu et al., (2018) and Ospina et al., (2020) where although cyclists consider factors such as vegetation and water bodies as a positive attribute, more weight is given to distance and travel times when choosing their commuting routes.

Also, we analyse the dataset using a point-biserial correlation (Spearman's rho) to look for the connections between characteristics

Table 5
Definition of usability variables based on Pelzer et al (2016) framework to evaluate tools involving public participation.

Variable	Definition
Transparency	The extent to which the underlying information and variables used in the tool are accessible and understandable to users.
Communicative value	The extent to which spatial/visual information is aptly presented.
User-friendliness	The extent to which participants are able to use the tool themselves.
Level of detail	The extent to which the level of detail of the tool matches the perspective of participants.
Integrality	The extent to which the tool takes all the relevant dimensions into account.

Table 6
Counts of SDFs preferences for usual and ideal routes with respective Spearman's rho correlation values. Values with * and ** are significant at the 0.05 level and 0.01 (2-tailed) respectively.

SDFs	Usual route count	Ideal route count	Times cycling per week (Usual/ Ideal)	Time living in study area (Usual/Ideal)	Confidence when cycling (Usual/Ideal)
Pavement quality	14	12	–	–	–
Adequate surface material	12	12	–	–	–
Wide cycling lane	8	10	–	(-0.571**/ -)	–
Independent cycling lane	9	8	–	–	–
Parking availability	1	1	–	–	–
Diversity of building's facades	6	5	–	–	–
Diversity of land use	3	7	–	–	(-0.610**/ -)
Street-level windows	3	2	(- /-0.469*)	–	–
Tall buildings	–	2	(- /-0.469*)	–	–
Trees	6	12	–	–	–
Grass/vegetation	3	9	–	(- /0.489*)	(-0.610**/ -)
Landmarks	5	3	–	–	(-0.472*/ -)
Water bodies	3	8	–	–	(-0.610**/ -)
Stop light avoidance	14	9	–	(0.444*/ -)	–
Least amount of road intersections	10	8	–	–	–

of the participants (i.e. cycling frequency, familiarity, and cycling behaviour) and the SDFs. The point-biserial correlation denoted to be the best fit for the dataset as the survey considered binary values to state the SDFs preferences for both usual and ideal routes and Spearman's correlation coefficients were chosen over Pearson's as Spearman's can evaluate a monotonic relationship within two variables (continuous or ordinal) rather than on a linear relationship such as in the case of Pearson's. From the results (Table 6), street-level windows and tall buildings show a negative correlation with the cycling frequency; this means that from the sample, the more people cycled per week the less likely they were to consider the presence of street-level windows and tall buildings to choose their ideal route.

For the case of the relationships of SDFs and the familiarity of the participants with the study area, results show that in the case of the usual route, participants that are more familiar with the area have more tendency to choose a route that avoids the most stop lights (positive correlation) but are less likely to consider the wideness of the cycling lane (negative correlation). In the case of the ideal route, participants that have more familiarity with the area tend to prefer the presence of grass or vegetation when considering their cycling routes as supported by the positive correlation. From the characteristics of participants, age and occupation are not shown in Table 6 as they did not show any meaningful correlation with SDFs.

With regard to the correlations between the confidence of participants while cycling (cycling behaviour typology) and SDFs, results show that there is a negative correlation with the diversity of land use and the presence of vegetation, water bodies and landmarks when choosing their usual route. This relationship means that participants with a higher confidence while riding have the tendency to not consider these SDFs when choosing their usual route. From the characteristics of participants, age and occupation are not shown in Table 6 as they did not show any meaningful correlation with SDFs.

5.2. *VR experiment: Influence of SDFs on cyclists' perception*

To allow comparison of results within the AoI of the different scenarios from the VR experiment, the recorded measurements for both fixation time and number of saccades were standardised (U_v) ranging from 0 to 1 using a min–max interval formula (equation 1). This resulting score follows a benefit criterion, meaning that the highest the value (closer to 1) the highest the fixation time or the number of saccades registered. The resulting values are shown in Table 7.

$$U_v = \frac{value - lowestvalue}{highestvalue - lowestvalue}$$

Equation 1. Min-max interval formula for standardised values.

Table 7
Standardised values for fixations and saccades based on the min (0/0) and max (77,608/169) values across scenarios.

	Front		Foreground		Context R		Context L	
Scenario	***Fixation***	***Saccades***	***Fixation***	***Saccades***	***Fixation***	***Saccades***	***Fixation***	***Saccades***
Bad	0.55	0.29	0.06	0.04	0.34	0.26	0.41	0.35
Average	0.70	0.33	0.04	0.02	0.38	0.27	0.25	0.17
Good	0.48	0.23	0.04	0.02	0.34	0.28	0.25	0.19
Scenic	0.37	0.16	0.02	0.01	0.45	0.38	0.38	0.33

Note: Standardised values are based on the average value for each of the measurements registered by participants (n = 22).

To improve the comparison between AoI across different scenarios, Fig. 4 illustrates in the form of a heat map the fixation times (red > 5 s) during the whole simulation (2 min per scenario) with an underlay of the AoI (magenta, blue, and yellow). The resulting shape of the heat maps reveals the patterns of participants' behaviour during the whole simulation for each scenario.

Similarities between the 'bad' and the 'scenic' shapes suggest that participants focused their attention on the front most of the time but also explored the context to both sides, as the horizontal shape of the heat map suggests. However, differences are spotted in the fixation scores. In the case of the 'bad' scenario, fixations to the front scored 0.55 against 0.37 in the 'scenic', meaning that participants paid more attention to the front in the 'bad' than the 'scenic' scenario. The similarities in behaviour between a 'bad' and a 'scenic' scenario suggest that the diversity of the scenery is not as influential as the specific features that a route has for specific sections to be categorised as boring or picturesque. This may happen as an environment with multiple buildings can be categorised as "boring". In contrast, a diverse path with different trees along the way may be categorised as "picturesque" even though both scenarios provide diversity.

Regarding the distribution of fixations represented for the 'average' scenario, the compact shape suggests that participants spent the most time looking to the front compared to other scenarios. This is also supported by the fixation score of the 'good' scenario as it scored the highest (0.70) compared to the other scenarios. This focus in the centre suggests that participants were not as interested in the context of average scenarios. Even though the 'average' scenario results regarding the context AOIs are very similar to the 'good' scenario regarding fixation (0.38, 0.25/0.34, 0.25) and saccades (0.27, 0.17/0.28, 0.19), differences are more understandable when comparing the fixation scores to the front AOI as the fixation score of the 'good' scenario (0.48) was smaller. This suggests that the motivation to rate between an average and a good scenario for participants may be the presence of ephemeral distractors such as the presence of pedestrians along the way.

5.3. Evaluation of the added value of the mixed-methods approach

The results from the added value survey are summarised in Fig. 5, differentiating both the Maptionnaire survey (MP) and the VR experiment (VR), scores in terms of learning and usability.

In terms of Learning, participants reported similar evaluations for both tools, suggesting that both have a similar potential to increase their users' awareness about how the experience may have influenced their route choices or what their attention is on while

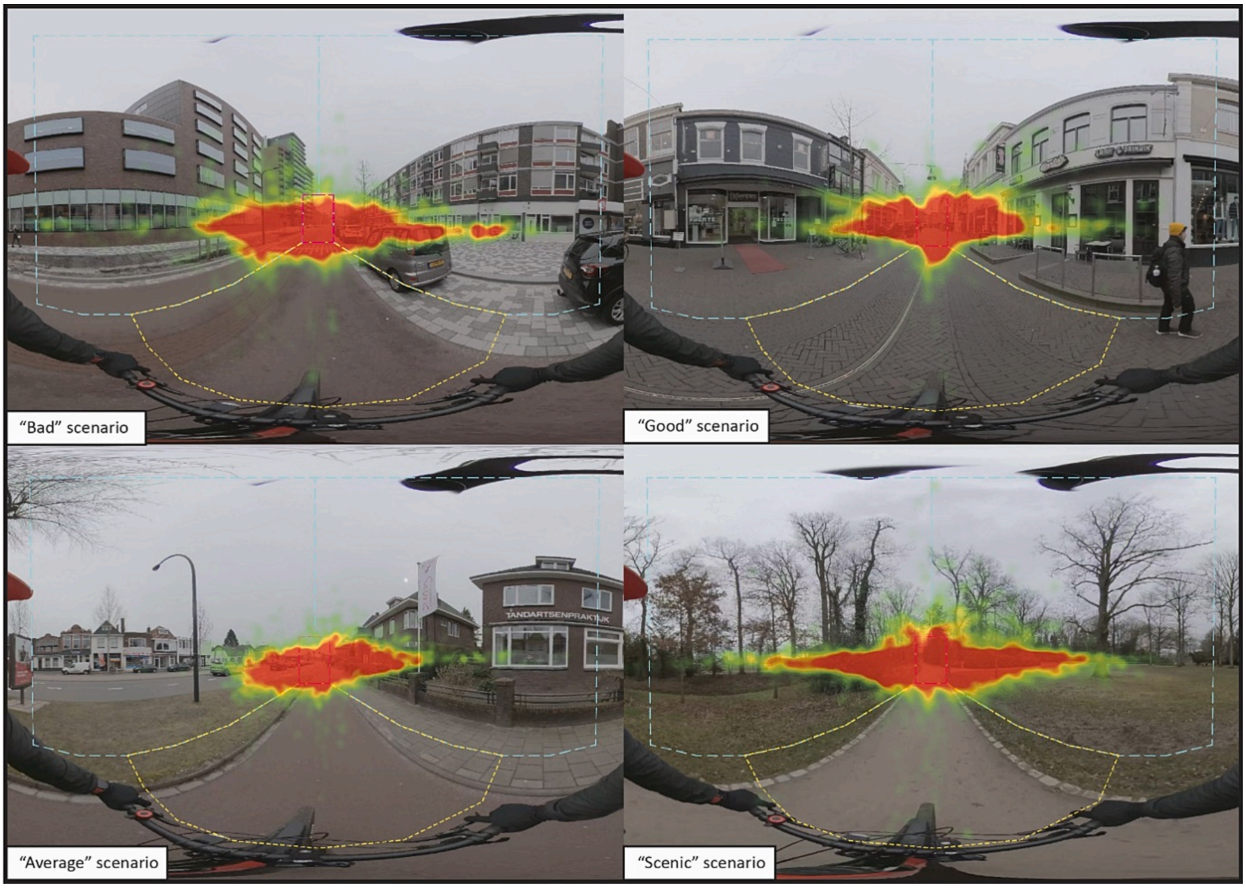

Fig. 4. Heatmaps of the bike ride scenarios with respective AOIs.

cycling. Even though the distribution of responses for both tools suggests a tendency for participants to be more aware of their reasons for choosing their commuting routes after using the tool, the use of the tool does not seem to have influenced as much the behaviour of participants while cycling. This means that after participating in the study, participants may present an increased awareness about how the design features of the streetscape influence their route choices but, it would probably not change the aspects they focus their attention on while cycling.

Regarding the change in criteria when choosing their commuting routes, results suggest that even though they may be more aware of how the SDFs play a role, there is a high chance for participants to keep their usual routes, which suggests that other factors such as distance or travel times may have a larger influence on their route choices. This behaviour is in line with studies that discovered that travel distances in cyclists' route choices are highly influential (Lu et al., 2018; Ospina et al., 2020).

As to the Usability of the implemented data collection tools, most participants reported very positive feedback about the ease of using both tools. This positive feedback suggests that both tools may increase the efficiency of collecting data considering larger samples. The representation of information for both tools was perceived positively, with a slight difference in the degree of understanding of variables involved where the Maptionnaire tool seems to have been more successful to represent the variables over the VR environment, even though both tools were reported to have the same level of detail. However, the VR tool seems to better capture the opinions about what participants find interesting about a cycling route. This output may be due to the eye-tracking capabilities involved in the VR experiment, which allows us to answer the question 'What do I find interesting while cycling?' in a more dynamic way for participants and without much effort.

6. Discussion

Regarding the influence of SDFs on cyclists' route choices, participants reported considerable differences between their usual and ideal commuting routes (section 5.1) where preferences towards avoidance of stop lights and good pavement quality were predominant in the usual routes against the preference for the presence of trees, vegetation, water bodies, and diversity of land uses in the ideal commuting routes. These preferences were also supported by the results from the eye-tracking measurements (section 5.2), where participants reported larger fixation times and saccades looking at the context in the 'scenic' scenario, meaning that they spent most of their time looking and exploring their surroundings that involved vegetation and trees along the way. In contrast, for the average scenario participants registered a larger fixation time looking to the front to elements such as crossings and stop lights.

These findings align with Winters et al. (2010), who also found that aesthetic amenities were influential in the enjoyment of the cycling experience. However, when it comes to the degree of influence that these elements may have when choosing a route, avoidance of stop lights and the quality of pavement may have the largest impact. This influence is supported by the findings of Lu et al., (2018) and Ospina et al., (2020) where although cyclists consider factors such as vegetation and water bodies as a positive attribute, more

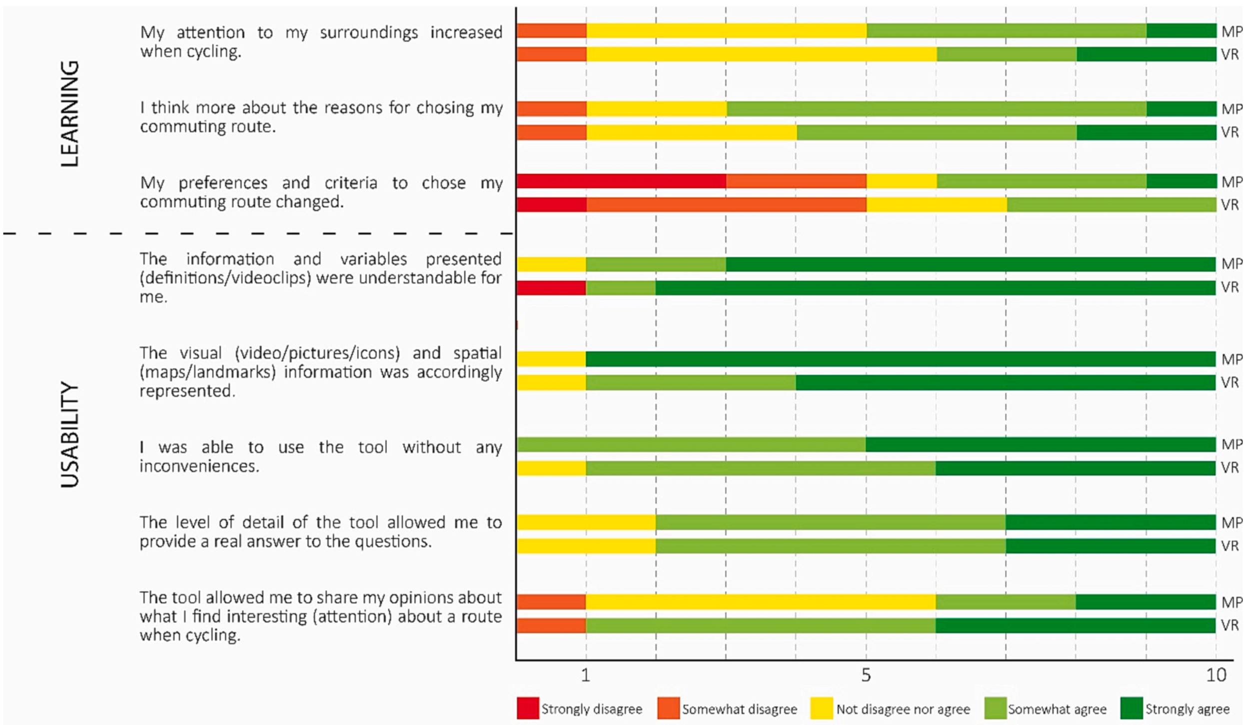

Fig. 5. Distribution of responses about learning and usability of the data collection tools.

weight is given to distance and travel times when choosing their commuting routes.

About the proposed methodology, mixing the results from both the survey and the VR experiment allowed us to gain more detailed information about how participants perceive SDFs and how they interact with them while cycling. The insights about the influence of SDFs in cyclists' route choices were supported on the one hand, by the survey that allowed us to explore the rationale of participants to choose their routes and help explain why they would categorise sections of their routes as 'bad' or 'beautiful'. This input provided subjective data from a bottom-up approach allowing us to analyse the influence of SDFs on their route choices, which may help understand the reasoning behind cyclists' route selection. On the other hand, the simulated bike ride and the measurement of participants' eye movements allow an understanding of how SDFs influence the perception in real-time (top-down approach) when cycling. These measurements allowed us to analyse participants' attention to design features and generate insights regarding how these may influence the overall riding experience in a given context.

The mixed-method approach of this study brings added value at the group and output levels. From the group level, the main advantage of using a mixed-method approach is that combining different methods allows for compensation in performance from each other in terms of efficiency, as the Maptionnaire survey seems to be better at enabling the exchange of information and collaboration among participants. In contrast, the VR and the eye-tracking experiment seem more efficient at providing deeper insights from a top-down approach. This means that using the combined methods may improve the efficiency of capturing data about cyclists' perceptions of SDFs without jeopardising the capabilities to reach a consensus and exchange information among participants to reach consensus.

As for the output level, the advantages of the proposed methodology can be seen in terms of the potential of the collected data for an improved understanding of the influence of SDFs in cyclists' route choices. The combination of eye-tracking measurements from certain sections with the responses from the survey allowed us to reflect upon the possible reasons to rate sections of the participants' routes as 'good' or 'bad'. This means that merging the results from different tools increases the chance to understand better how cyclists interact with the SDFs and how these influence their perceptions and choices when cycling.

7. Conclusions

Understanding the route choices of cyclists and their motivation based on their preferences is important to improve cycling networks and encourage the use of active travel modes such as cycling. In this study, a mixed-method approach (a combination of bottom-up & top-down approaches and a final evaluation) was developed to understand the influence of SDFs on cyclists' route choices.

Even though several studies address perceptions using similar tools to identify the design elements (i.e. Alattar et al., 2021; Nazemi et al., 2021), they often focus on one type of perception rather bottom-up or top-down with the use of surveys, interviews, or analytical models. However, this study's findings suggest that combining different methods may improve the understanding of how cyclists interact and are influenced by the already identified SDFs.

Due to the opposite nature of the bottom-up and top-down approaches for the observation of perception, using a mixed-method approach was considered appropriate as the combination of results from both perspectives allowed us to further understand how the SDFs influence the cycling experience. The survey allowed us to explore the reasoning of participants to choose their routes and explore the rationale to consider sections of their routes as 'bad or boring' or 'beautiful'. This type of comment allows one to understand the influence of the design features based on their personal experiences, which may be useful to further understand the reasoning behind route selection from a top-down approach. A simulated bike ride and the measurement of participants' eye movements allowed us to understand how SDFs influence the perception in real-time when cycling. These measurements allow us to analyse the attention of participants to design features and how these may influence the overall riding experience in a given context from a top-down approach.

The combination of these two methods to collect data about the perception of SDFs allowed us to contextualise the retrieved information as data from sections within the study area was collected from participants that were familiar with the environment. This familiarity aspect allowed focusing the attention on the enjoyability of the ride when participating in the VR experiment and consequently, after mixing results from both methods, gain detailed information about how participants perceive SDFs and how they interact with them when cycling. Therefore, this approach may be valuable to address targeted interventions or to receive feedback from participants about a specific context from both their previous experiences and their interaction in real-time with the environment.

This study contributes to existing literature regarding the influence of SDFs on cycling behaviours as our findings suggest cyclists tend to focus their attention on diverse and changing environments while cycling. This means that participants reported a preference for design features that enhanced the aesthetics of their routes such as trees, diverse facades, presence of vegetation and water bodies. However, these preferences may just influence the enjoyability of the ride but would not have more importance over shorter travel times when it comes to commuting. These revealed preferences may be also useful for decision-makers to develop interventions of infrastructure to reward cyclists and therefore encourage the use of the bicycle in specific urban environments.

According to the evaluation of the added value of the mixed-method approach, participants showed an increased level of awareness about the reasons to choose their commuting routes. However, this increase in awareness seems not to have influenced the preferences or criteria of participants to change their routes after participating in the study. This means that after participating in the study, participants reflected on their responses and the way they interact with their surroundings when cycling. This potential for increasing understanding from the mixed-method approach may be useful for decision-makers and researchers to gain insight into specific interventions regarding SDFs or to improve the cycling infrastructure from a data-driven perspective.

Additional advantages of the implementation of the mixed-method approach can be found in the potential of the collected data to improve understanding of the influence of SDFs in cyclists' route choices. The increased potential may be due to the combination of eye-tracking measurements from certain road sections and the responses from the survey which allow reflection upon the reasoning to rate sections as 'good' or 'boring'. This means that, by merging the results from different tools, there is an increasing chance to better understand how cyclists interact with the SDFs and how these influence their perceptions and choices when cycling.

This study has limitations that might be useful for future research. Regarding technical limitations, several trade-offs had to be considered when developing the VR experiment that may have influenced the behaviour and eye movements of participants. Considerations about processing power, more stable software and quality of video clips (higher resolution, frames per second and bit rates) could impact the experience of participants as the stimuli would feel more natural and immersive, allowing for better measurements of their attention to AOIs during the simulation of a bike ride.

Additionally, limitations in the case of the research design involve the consideration of a larger and more diverse sample size for both the survey and the experiment. This diversity may be introduced by not considering a single common destination but an area such as the city centre to retrieve more information about the bicycle infrastructure of the whole study area from inhabitants and visitors. Also, introduces more possibilities to comment on specific SDFs that may have been left out from the literature that was used in this study, as these missing elements may have an influence when choosing a route.

This paper addresses the difficulty to capture perceptions by considering both the bottom-up and top-down approaches to improve the interpretation of the retrieved information and discusses the advantages and limitations of the proposed mixed-methods approach. Results from this study may encourage future studies to develop and implement alternative mixed-methods approaches to increase understanding of cyclists' travel behaviour regarding route choice. Also from a practitioner's perspective, implementation of such mixed methods for data collection may increase the efficiency of the process and also help to develop contextual data-driven interventions that aim to encourage the use of bicycles.

CRediT authorship contribution statement

Roberto Nacxit Ramirez Juarez: Conceptualization, Methodology, Software, Formal analysis, Investigation, Resources, Data curation, Writing – original draft. **Anna Beatriz Grigolon:** Conceptualization, Methodology, Validation, Resources, Writing – review & editing, Supervision, Project administration. **Ana Mafalda Madureira:** Conceptualization, Methodology, Validation, Resources, Writing – review & editing, Supervision, Project administration.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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