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What is a good design for a cycle street? – User perceptions of safety and attractiveness of different street layouts

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ABSTRACT

Cycle streets have been implemented in many urban areas around the world in recent years to make cycling safer and more attractive. In these streets, cyclists have priority over motorised traffic. They are allowed to use the entire roadway and determine traffic speed. However, there have been no standardised design guidelines for cycle streets to date. Moreover, there is limited understanding of the individual perception of different cycle street designs. Yet, positive evaluations of safety and attractiveness are especially important for pleasant travel in public spaces. Therefore, this study examines the individual perceptions of three cycle street designs: *conventional*, *flow* and *shared space*. Visualisations of these designs were implemented in a written household survey conducted in the urban Rhine-Main metropolitan region in Germany (n = 701). Participants were asked to assess the different designs in terms of safety, clarity, attractiveness and fun. Furthermore, bivariate analyses and regression models were performed to investigate whether individual travel preferences and attitudes, regular mode use and socio-demographic characteristics affect assessments of the designs. The results show that the *shared space* design is rated as the safest, most attractive and most fun. The *conventional* cycle street is evaluated as the most clearly structured. Individual affinity towards cycling and walking favours a good evaluation of the *shared space* design, while a high car affinity and having a migrant background positively affect the assessment of the *conventional* design. In addition, younger participants and members of households without a car assess the *flow* design more favourably.

1. Introduction

In recent decades, populations in cities have grown rapidly and so has traffic in these urban spaces (Rode, 2013). Consequently, more and more residents of urban environments face "limited space, obstacles, noise, pollution, risk of accident and other disgraceful conditions" (Gehl, 2010, p. 3). At the same time, research shows the high impact that the urban environment has on human well-being. Discussions about factors influencing the quality of urban life have resulted in various urban concepts focussing on human demands being developed. These concepts aim to meet the challenges raised by the *car orientated town* (Reichow, 1959), which has been taken into account in the construction of many cities. In this context, the promotion of cycling has increased in recent years in many countries and cities (Buehler and Pucher, 2012; Carstensen and Ebert, 2012; Lanzendorf and Busch-Geertsema, 2014). Local governments supporting cycling pursue goals to enhance quality of life, such as improving people's health and the mitigation of climate change (Banister, 2011). Measures to make cycling more safe, convenient and attractive include the implementation of cycle paths, bicycle parking, integration with public transport and communication concepts (Pucher and Buehler, 2008; Hull and O'Holleran, 2014).

Improving cycling infrastructure by means of cycle streets – also known as bicycle boulevards – is a cost-effective option that does not require additional space (Walker et al., 2009). Even if there is no standardised definition of cycle streets, the common goal of the different approaches is to give priority to cyclists (Parkin, 2018). This often means that cyclists can use the entire road. Nevertheless, cyclists mostly share the street with motorised traffic. In Germany, national traffic regulations ('Straßenverkehrsordnung') determine the following regulations of cycle streets: (i) no obstacles should impede bicycles' movement or safety, (ii) cyclists are permitted to ride side by side, (iii) motorised vehicles are only allowed to pass cycle streets in exceptional cases, indicated by an additional traffic sign and (iv) the speed limit is 30 km/h (StVO, 2013). Accordingly, the focus of a cycle street's design is on cyclists instead of motorists in order to improve cycling safety and attractiveness (Graf, 2018; Parkin, 2018).

Despite the fact that there is increasing implementation of cycle streets worldwide, there has been relatively little research on this

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infrastructure measure so far (Denvall and Johansson, 2013; Mead et al., 2014; Eder, 2017). Related studies mainly concentrate on cycle street awareness (Alrutz et al., 2016; Eder, 2017; Blitz et al., 2020), acceptance (VanZerr, 2010; Manser et al., 2018) and use (Khut, 2012; Dill et al., 2014; Blitz et al., 2020) by residents as well as on safety issues concerning accidents (Minikel, 2012; Manser et al., 2018) and speeding (Alrutz et al., 2016; Surkan, 2016; Manser et al., 2018). To the best of our knowledge, to date there has been no research on comparative individual evaluations of different cycle street designs and related perceptions of safety and attractiveness. To bridge this research gap, the study evaluates three different cycle street design options in a typical inner-city residential area with perimeter block development: *conventional*, *flow* and *shared space* designs. The *conventional* design only shows minor changes related to on-street markings and signs indicating the cycle street's regulations. Car parking spaces can still be found all along the pavements. As a result, there is a clear separation of the roadway provided for bicycle as well as car traffic and the pavements intended for pedestrians. The *flow* design involves fewer car parking spaces, but more space for bicycle parking, trees, pavements and markings in noticeable colours. The roadway runs a slight curve. The *shared space* design has no strict separation of travel modes and no on-street markings for car parking. Instead, more greenery, water elements and spaces to linger come into focus. Motorised and non-motorised travel modes jointly use the roadway (details and illustrations in Section 3.2). We included graphically illustrated design scenarios in a written household survey (n = 701), which was conducted in the city of Offenbach am Main situated in the Rhine-Main metropolitan region in Germany. By analysing the respondents' subjective perceptions of the different designs, this study addresses the following three research questions: (i) "How do the participants evaluate the safety, clarity, attractiveness and fun of the different cycle street designs?", (ii) "How do individual mobility preferences affect the evaluation of the designs?" and (iii) "Which respondents feel attracted to the different designs?". Answers to these questions may give further hints to improve cycle street design and, thus, enhance cycling and the quality of urban space in cities. Furthermore, the analyses shed some light on the tension between the clarity and safety of *shared space* concepts.

The structure of the paper is as follows. Section 2 summarises theories on safety and attractiveness as basic factors of an urban environment. Furthermore, it introduces the concept of *shared space* as a means of people-orientated city planning. Next, Section 3 describes the case study and the sample in the survey. Section 4 presents the results based on descriptive, bivariate and multivariate analyses of the survey's data. We use multiple linear regression to answer the third research question. The paper continues with a discussion in Section 5 and closes with conclusions in Section 6.

2. Theoretical background: The safety and attractiveness of urban street design

2.1. Safety in the local environment

Feeling safe is a crucial need for human beings allowing them to act more comfortably, freely and effectively in their local environment (Flade, 2008; Gehl, 2010). Thus, safety fosters one's own abilities to orient oneself and to cope with unexpected situations. By contrast, feeling unsafe can lead to avoidance (van der Burgt, 2015; Bennetts et al., 2017). This comes along with severe consequences for the use of urban space and individual travel behaviour, e.g. individual transport mode and route choice. Safety can be measured using objective quantifiable criteria as well as subjective perceptions (von Wirth et al., 2015; Ettema and Schekkerman, 2016). Even though the subjective dimension is often neglected, considering the user's individual perception is important, since there is often a discrepancy between objective and subjective safety. For example, even if accident rates in a certain area are low, people may feel unsafe because of perceived conflicts or self-experienced accidents (Klebelsberg, 1982).

Research shows that people feel unsafe in places that impede one's view on all sides and that offer no protection (Fisher and Nasar, 1992). If a place is obscured and without refuges, feelings of subjective safety depend on the possibility to escape. Further characteristics of space having an influence on perceptions of safety are signs that indicate *dilapidation* (Skogan, 2015). These include vandalism, graffiti, dirt and waste evoking the impression of a lack of control and social disorder and are linked to feelings of unsafety and fear of crime (Perkins et al., 1993). In contrast, lively, light and clean urban spaces indicate a high level of safety (Gehl, 2010). These correlations could also be found in a number of studies on safety perceptions in transportation settings and spaces, such as railway stations (Sundling and Ceccato, 2022). For instance, Kim (2021) and Cozens et al. (2003) point out the importance of spatial visibility and adequate lighting to enable people to notice potential risks and opportunities for escape. Moreover, Coppola and Silvestri (2020) as well as Loukaitou-Sideris (2014) show that the perception of busyness, for example due to the presence of commercial activities and other passengers, contributes to a feeling of safety.

The feeling of safety in public spaces also plays a major role with regard to cycling (Willis et al., 2015). In Germany, for example, only approximately half of cyclists mostly feel safe (Gehlert and Genz, 2011; Sinus, 2019). This varies by socio-demographic characteristics, such as gender (women are more likely to feel unsafe) and age (older people in particular feel unsafe). Furthermore, factors such as high traffic volumes, conflicts with car drivers and speeding reduce subjective safety. Consequently, a majority of cyclists want policymakers to implement safe bicycle infrastructures (Sinus, 2019).

2.2. Attractiveness of the local environment

In addition to safety, the influence of the built environment on humans has further dimensions. Various studies prove its effects on mental health, i.e. stress, relaxation, well-being and attention (Ettema and Schekkerman, 2016; Bilotta et al., 2019). Thus, the design of a street has the potential to increase the quality of stay and to encourage people to visit this space or to make people feel better during their everyday travel. Therefore, attractive local environments make active mobility more enjoyable and viable and additionally create places of high quality and a *sense of space* (Handy et al., 2002; Timms and Tight, 2010). Two theoretical approaches explain individual assessments of environments: (i) evolutionary and (ii) cultural theories (Tveit et al., 2019).

Evolutionary theories suggest that people prefer environments that increase the probability of survival: the more familiar and organised an environment is and the easier to understand, the better people evaluate this space (Kaplan et al., 1989). This shows a strong link between safety and attractiveness. Kaplan et al. (1989) derive four factors that influence the attractiveness of environments: (1) coherence, which they describe as understanding how environmental elements result in a common whole, (2) complexity that summarises the number and diversity of elements, (3) legibility that means ease of orientation and building a cognitive map and (4) mystery, which describes an environment full of expectations to explore new things. The last factor seems to be the most reliable predictor of attractiveness (Kaplan et al., 1989). Berlyne's (1971) experiments prove the effects of such local environment characteristics on human perception and their *aesthetic evaluation*. Since people find very simple environments boring, they seek other stimulations in order to compensate for insufficient mental workload. Complex environments, on the other hand, overload people's mental work capacity. Thus, environments should address the optimal amount of *human information processing*.

Cultural theories explain environment assessments with cognitive processes, such as cultural and socially formed attitudes. Important factors are the familiarity of places (Tuan, 1990) and ecological knowledge about them (Carlson, 2009). Empirical research supports evolutionary theories in the form of a high universality of environment assessments (Kaplan and Kaplan, 1989; van den Berg and Koole, 2006; Tveit et al., 2019) that are simultaneously influenced by cultural and social elements (Yu, 1995; Strumse, 1996; van den Berg et al., 1998; Tveit, 2009). Thus, Tveit et al. (2019) suggest the development of an integrated approach addressing both theories.

Previous studies show that there are specific elements that make streets and local environments more attractive. Especially, nature elements are associated with individual well-being: greenery and water increase positive perceptions of the environment, reduce stress and have mood-enhancing effects (Karmanov and Hamel, 2008; Tveit et al., 2019). Moreover, green areas enhance social interaction (Coley et al., 1997), social cohesion and intercultural social encounters (Peters et al., 2010). In contrast, less green space in residential environments contributes to people‘s feelings of loneliness and shortage of social support, especially for low-income people, the elderly and children (Maas et al., 2009). Furthermore, a spacious and coherent design has a positive influence on well-being (Karmanov and Hamel, 2008). Street designs address these factors in different ways. A concept that considers subjective safety and attractiveness in an innovative way is *shared space*.

2.3. Shared space and its challenges

Shared space has become a much discussed approach to urban street design that does not aim for traffic separation (Kaparias et al., 2015; Ruiz-Apilánez et al., 2017). Instead, street users – whether motorised or non-motorised – should be encouraged to equally and collectively use the street and to interact with each other (Hamilton-Baillie, 2008). As a result, a high quality street environment should be created not only for car users but also for pedestrians, cyclists and residents. While in conventional street designs, the street is primarily dedicated to motorised traffic in order to facilitate smooth and rapid access to destinations (Homburger, 2002; Gehl, 2010), thus, *shared spaces* themselves become destinations and places to stay (Karndacharuk et al., 2014). Based on the broader philosophy of the UK's Buchanan Report (Ministry of Transport, 1963) and further developed in the Netherlands, the *shared space* concept made its entrance into urban street designs worldwide since the 1960 s (Imrie, 2012; Karndacharuk et al., 2014). To date, different definitions and terms have been used, such as *shared street*, *encounter zone* and *woonerf* (Ruiz-Apilánez et al., 2017). Karndacharuk et al. (2014) suggest the following definition:

> "A public local street or intersection that is intended and designed to be used by pedestrians and vehicles in a consistently low-speed environment with no obvious physical segregation between various road users in order to create a sense of place, and facilitate multi-functions." (p. 215)

To ensure traffic safety despite joint use by non-motorised and motorised users, the concept aims to provoke subjective uncertainty in order to make people attentive and act more carefully and slowly (Adams, 2012). For this purpose, separation elements, such as barriers, kerbs, markings and traffic signs are removed to force people to negotiate and communicate with each other directly (Hamilton-Baillie, 2008). As a result, *shared spaces* might provoke more traffic conflicts, but not necessarily more accidents. However, even with no conventional traffic signs, the design of the *shared space* street needs to indicate its rules (Karndacharuk et al., 2014) and to nudge certain behaviour (Thaler and Sunstein, 2009), such as moving carefully and slow speed (Engwicht, 2005). Certain elements, such as trees, benches and a consistent surface, help to achieve this and at the same time may increase the street's attractiveness and amenity (Edquist and Corben, 2012; Karndacharuk et al., 2014; Ruiz-Apilánez et al., 2017). Gehl (2010) points out that the *shared space* concept is only successful if the design is based on the safety requirements of the slowest travel mode, the pedestrians. However, he argues that the constant alertness that is necessary is at the expense of carefree mobility and, thus, of amenity and pleasantness.

Recent studies in several European and North American cities on the effects of *shared space* indicate that its implementation increases the safety and comfort for pedestrians due to fewer accidents, fewer pedestrian-vehicle conflicts and lower speeds (Kaparias et al., 2013; Curl et al., 2015; Ruiz-Apilánez et al., 2017; Frosch et al., 2019). However, some investigations in *shared spaces* show high numbers of pedestrian-cyclist incidents, especially in crowded areas (Beitel et al., 2018; Gkekas et al., 2020). Therefore, several studies on cycling infrastructure highlight the importance of travel mode separation to increase safety (Buehler and Pucher, 2012; Li et al., 2012; ADFC, 2021). In his research, Duncan (2017) questions any effects of *shared space* design on cycling, observing that cyclists do not differ in their behaviour in *shared space* and conventional streets. In both spaces, they primarily ride along the edges, which makes the author recommend an increase in lateral rideable space. Altogether, this illustrates the high demands on the design of the local environment to satisfy objective and subjective safety needs as well as the attractiveness ideals of different road users.

3. Research design

3.1. Survey and case study

In order to analyse the safety and attractiveness of different street designs, we developed a quantitative household survey focusing on travel behaviour and attitudes as well as the assessment of cycle streets. The survey was conducted in March and April 2019 in Offenbach am Main, near Frankfurt am Main in the Rhine-Main metropolitan region in Germany. It addressed 4,014 households in two neighbourhoods of a dense urban area. Like large parts of the inner city, the cityscape of the investigation area is mostly characterised by perimeter block developments with sporadic commercial first floor use and only a few green spaces or vegetation (Stadt Offenbach am Main, 2016). Due to on-street car parking, the streetscapes are dominated by car traffic. The city's main railway station is in the centre of the survey area. Each household received a twelve-page questionnaire requesting one randomly selected adult household member to participate.

We chose Offenbach am Main as a case study due to its ambition to enhance cycling with the introduction of 9 km of cycle streets between 2019 and 2021 (Fig. 1). The cycle streets are part of six in the city centre meeting main cycling axes linked to existing cycling infrastructure and covering important connecting routes to destinations in the city and neighbouring municipalities (Stadt Offenbach am Main, 2018). These include direct connections to the city's main station, the pedestrian zone, several schools, local recreation areas and a well-developed bicycle path to Frankfurt. Confronted with high population expansion throughout the region (Stadt Offenbach am Main, 2019b), Offenbach wants to counter congestion due to higher traffic volumes by facilitating safe and convenient cycling. With an increase in non-motorised travel modes, the city aims to reduce air pollution and improve the local environment's attractiveness (Stadt Offenbach am Main, 2018).

About 6 months prior to the survey, the city's first cycle street 'Senefelderstraße' was implemented in the survey area as a test route to demonstrate and evaluate its specific concept. Here, cyclists are prioritised and are allowed to ride next to each other. Speed is limited to 30 km/h. Car use is only permitted for residents and visitors (Stadt Offenbach am Main, 2018). 'Senefelderstraße' itself is a typical urban residential street with a dense building development and on-street car parking. The street is planned to be part of the cycling route network. Hence, 'Senefelderstraße' is linked to streets with existing bicycle lanes and to designated cycle streets. However, the conventional design of 'Senefelderstraße' has not changed much. Only traffic signs and markings indicate the new regulations. Additionally, an information campaign has accompanied the implementation. The transferability of the cycle street's design options in such a typical urban context to other streets makes selecting this case study relevant to other areas.

3.2. Cycle street designs

The survey's participants were asked to evaluate three urban cycle street designs by means of illustrations in the questionnaire: (i) *conventional*, (ii) *flow* and (iii) *shared space* (Fig. 2). The designs were developed in cooperation with the Offenbach University of Art and Design (HfG Offenbach) (Albrecht and Eckart, 2020).

The *conventional* cycle street is the design that was implemented with its introduction in the investigation area indicated by only adding traffic signs and on-street markings. In this street, there is a clear separation of travel modes. The car parking areas separate the roadway from the rather narrow pavements provided for pedestrians. Dashed white and blue markings indicate the dooring zones of the parked cars on both sides of the street. The roadway is straight. In contrast, the roadway of the *flow* design runs a slight curve. The travel modes are still separated by pavements. However, the markings indicating the dooring zones differ from those of the *conventional* design, the pavements are widened and parking areas for cars are not present along the entire street. Instead, several trees are placed along the roadside and cyclists as well as pedestrians with children come into the field of vision. This is also the case with the *shared space* design. In addition, further greeneries and vegetation, water elements, benches and bicycle parking facilities can be seen. The illustration shows no strict separation of travel modes, no on-street markings for parking spaces or dooring zones. Cyclists, pedestrians and car users share the same street spaces. The ground is covered with coloured paving instead of grey asphalt. Children are playing in the middle of the street. In contrast, cars have almost disappeared from the scene.

The three designs differ in terms of safety and attractiveness characteristics. The parked cars in the *conventional* design cover up the pavements impeding a clear view of the street from the pavement. Thus, eye contact and communication between pedestrians and cyclists or car drivers are difficult, which may cause uncertainty. On the other hand, the parked cars offer protection from the traffic on the street. In contrast, the reduced number of cars and the accompanying less clear separation mean that eye contact and communication are easier with the *flow* and *shared space* designs. While the *conventional* design enables unhindered, straight and, thus, fast travel on the street, the other two designs indicate

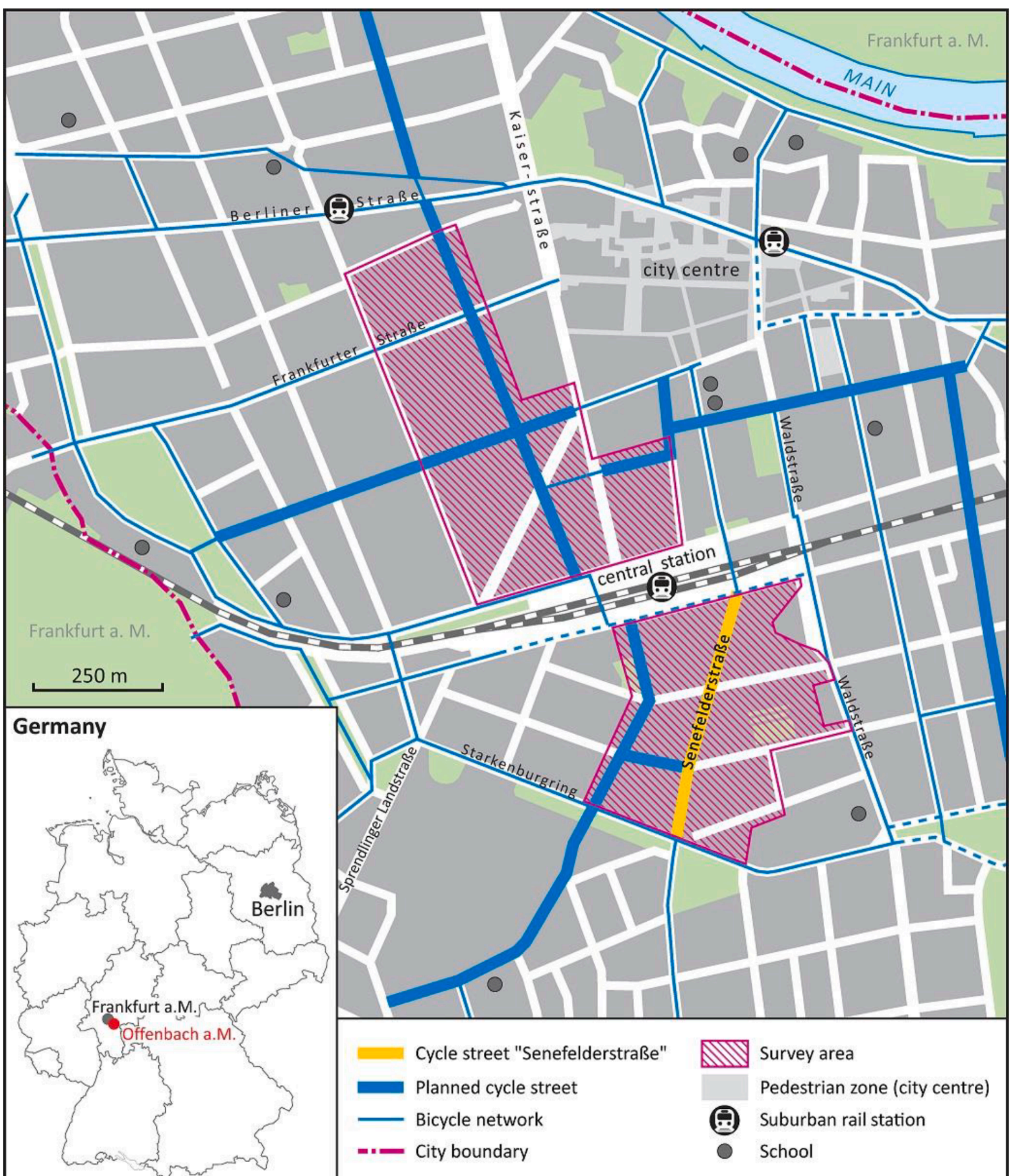

Fig. 1. Bicycle network with the "Senefelderstraße" cycle street and survey area in Offenbach am Main (cartography: Elke Alban, Goethe University Frankfurt/Main).

(i) *Conventional* design

(ii) *Flow* design

(iii) *Shared space* design

Fig. 2. Conventional, flow and shared space cycle street designs (Illustrations: Janina Albrecht, HfG Offenbach, see Albrecht and Eckart (2020)).

slower speed. Here, the green elements offer shelter and retreat possibilities in order to enhance sociability (section 2.2.). The presence of people on the street indicates liveliness and, thus, that using the street is safe and reasonable (Gehl, 2010). The vegetation, bench and water elements in the *shared space* design contribute to the street's appeal and even give the impression of a place to linger. Here, the built environment is clearly more complex than in the other two designs. An increasing number of details comes into focus. This characteristic refers to mystery according to Kaplan and Kaplan (1989) eventually increasing attractiveness. In contrast, the built environment of the *conventional* design is simple and non-complex, improving legibility and, thus, the ease of orientation (Kaplan and Kaplan, 1989).

3.3. *Sample*

Of the 4,014 households addressed, 706 questionnaires returned (response rate 17.6%). A total of N = 701 questionnaires are considered in the analysis (questionnaires with more than 70% missing values were rejected). Regarding the socio-economics (Table 1), women and men make up almost the same proportion. The mean age value is 46 years and, thus, about six years higher compared to the entire city's official statistics, which, however, also include inhabitants under the age of 18 years. About three quarters of the respondents have a higher education entrance qualification. A similar share is employed or in education. The mean monthly net income is €2,113. 26% of the participants have a migrant background, a value significantly lower than the city average (63%). 14% of the respondents live in households with children under the age of 14, 69% in households with at least one car. Furthermore, statistics on regularly used travel modes show that the same proportions of participants (59%) use a bicycle or car at least once a week. Four out of five make walking trips frequently.

Table 1
The sample's socio-economics and travel mode use compared to the city's entire population.

Variable	Description	Sample (Mean) n = 701	Offenbach (Mean) n = 138,853[1]
Socio-economics			
Female	gender: female (1); male (0)	51%	49% [1]
Age (mean value)*	age in years (18–96)	46 years	40 years [2]
Higher education entrance qualification	Abitur/A levels: yes (1); no (0)	74%	no data
Employed/in education	employed (full-time/ part-time) or in education/ school/college: yes (1); no (0)	77%	no data
Monthly net income (mean value)	income in euro [3] (139–5500)	€2,113	no data
Migrant background*	with a migrant background [4]: yes (1); no (0)	26%	63% [1]
Children in household	at least one child under 14 in household: yes (1); no (0)	14%	no data
Household with car ownership	at least one car in household: yes (1); no (0)	69%	no data
Regularly used travel modes			
Bicycle	bike use at least once a week: yes (1); no (0)	59%	no data
Car	car use at least once a week: yes (1); no (0)	59%	no data
Walking	walking trips over 3 min at least once a week: yes (1); no (0)	80%	no data

* significant difference between total sample and city of Offenbach's total population (binomial test, p <.010).
[1] Stadt Offenbach am Main (2019b).
[2] including the population under the age of 18 (Stadt Offenbach am Main, 2019a).
[3] quotient of the mean value of the stated monthly net household income (queried using the levels: less than €1,000; €1,000 to less than €2,000; €2,000 to less than €3,000; €3,000 to less than €4,000; €4,000 to less than €5,000; €5,000 and above and the number of household members adjusted according to the OECD-modified scale: 1 adult valued 1.0 members, further adults 0.5 members, children under 14 0.3 members (OECD, 2013)).
[4] respondent's country of birth or his/her parent's country of birth different to Germany.

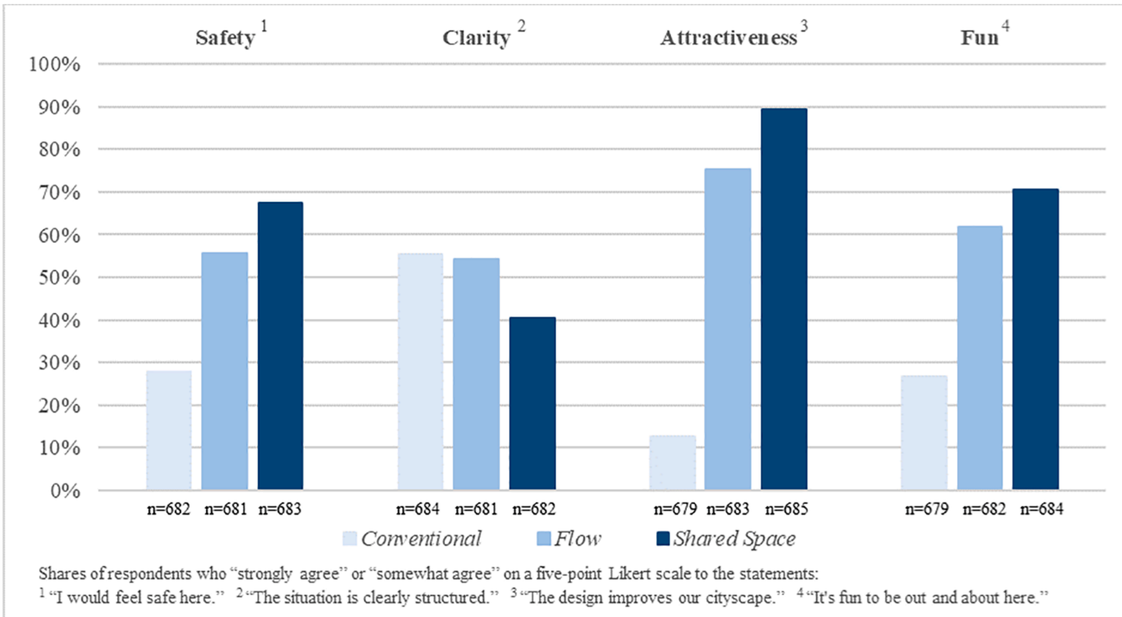

Fig. 3. Descriptive results on evaluations of the three cycle street designs.

4. Results

4.1. Evaluation of safety, clarity, attractiveness and fun of the three cycle street designs

In this section, we show how the respondents evaluate safety, clarity, attractiveness and fun of the *conventional* compared to the *flow* and *shared space* designs. For this purpose, the respondents assessed four statements for each cycle street design: (i) "I would feel safe here." (safety), (ii) "The situation is clearly structured." (clarity), (iii) "The design improves our cityscape." (attractiveness) and (iv) " It's fun to be out and about here." (fun). Descriptive results show that the participants evaluate *shared space* as least clearly structured but, at the same time, the best safety, attractiveness and fun compared to the other designs (Fig. 3). Conversely, the *conventional* design is perceived as best for clarity but worst for safety, attractiveness and fun. Furthermore, the *flow* design is much better assessed for safety, attractiveness and fun than the *conventional* one.

An analysis of variance with repeated measures shows that these differences in the assessments of the four indications are significant[1,2]. For safety assessment, Bonferroni-corrected pairwise comparisons show that the five-point Likert scale evaluations of *conventional* and *flow* are significantly lower than that of *shared space*. Furthermore, safety in *conventional* design is significantly lower than in *flow* design. While no significant difference in the assessments of clarity can be found between *conventional* and *flow* design, both are significantly higher than for *shared space*. Analyses also show that the evaluation of the attractiveness of *conventional* design is significantly lower than that of *flow* design and of *shared space*. In addition, attractiveness in *flow* design is significantly lower than in *shared space*. Finally, the fun of *conventional* and *flow* design is assessed significantly lower than that of *shared space* and it is significantly lower in *conventional* design than it is in *flow* design.

Pearson correlation analyses show that for all three designs all four assessments positively correlate with each other. Particularly high coefficients result for clarity and safety (*conventional*: $r = 0.572$, $p < .01$; *flow*: $r = 0.607$, $p < .01$; *shared space*: $r = 0.598$, $p < .01$) as well as for fun and safety (*conventional*: $r = 0.771$, $p < .01$; *flow*: $r = 0.787$, $p < .01$; *shared space*: $r = 0.792$, $p < .01$).

4.2. The impact of individual mobility preferences on the assessments of the designs

Participants were asked to rate their individual preferences on three mobility characteristics, which are also influenced by street design: (i) safety, (ii) pleasantness of the environment and (iii) speed when travelling. As Fig. 4 shows, all three characteristics are considered important by the majority of the respondents. This applies to pleasantness in particular.

The analysis of variance with repeated measurements shows that respondents with different evaluations of the importance of speed when travelling differ regarding their overall assessment of the three designs[3,4]. A significant between-subjects effect can be seen related to the evaluations of designs 1 and 3 ((F 2, 664) = 3.71, p <.05). This indicates that the importance of speed has an effect on people's ratings of these designs: people who strongly agree to the item "It is important to me to reach my destination as quickly as possible." significantly evaluate the *conventional* design better than people who do not consider speed as important. The evaluation of the *shared space* scenario shows an opposite effect. Respondents who indicate speed as not important while travelling

[1] Repeated measures ANOVA with a Greenhouse-Geisser correction indicated that mean performance levels showed a statistically significant difference between measurements for each assessment. Safety: F(1.77, 1196.05) =184.68, p =.00; Clarity: F(1.74, 1174.76) =19.48, p =.00; Attractiveness: F(1.76, 1186.86) =1101.86, p =.00; Fun: F(1.78, 1199.13) =217.40, p =.00.

[2] For each assessment, Mauchly's test indicated that the assumption of sphericity had been violated. Safety: χ^2 (2) = 92.87, $p < .05$; Clarity: χ^2 (2) = 108.88, $p < .05$; Attractiveness: χ^2 (2) = 98.20, p <.05; Fun: χ^2 (2) = 87.80, p <.05. Therefore degrees of freedom were corrected using the Greenhouse-Geisser adjustment. Safety: $\varepsilon = 0.89$; Clarity: $\varepsilon = 0.87$; Attractiveness: $\varepsilon = 0.88$; Fun: $\varepsilon = 0.89$.

[3] Repeated measures ANOVA with a Greenhouse-Geisser correction indicated that mean performance levels showed a statistically significant difference between measurements: F(3.54, 1174.05) = 3.07, $p < .05$).

[4] Mauchly's test indicated that the assumption of sphericity had been violated: χ^2 (2) = 93.19, $p < .000$. Therefore degrees of freedom were corrected using the Greenhouse-Geisser adjustment: $\varepsilon = 0.88$.

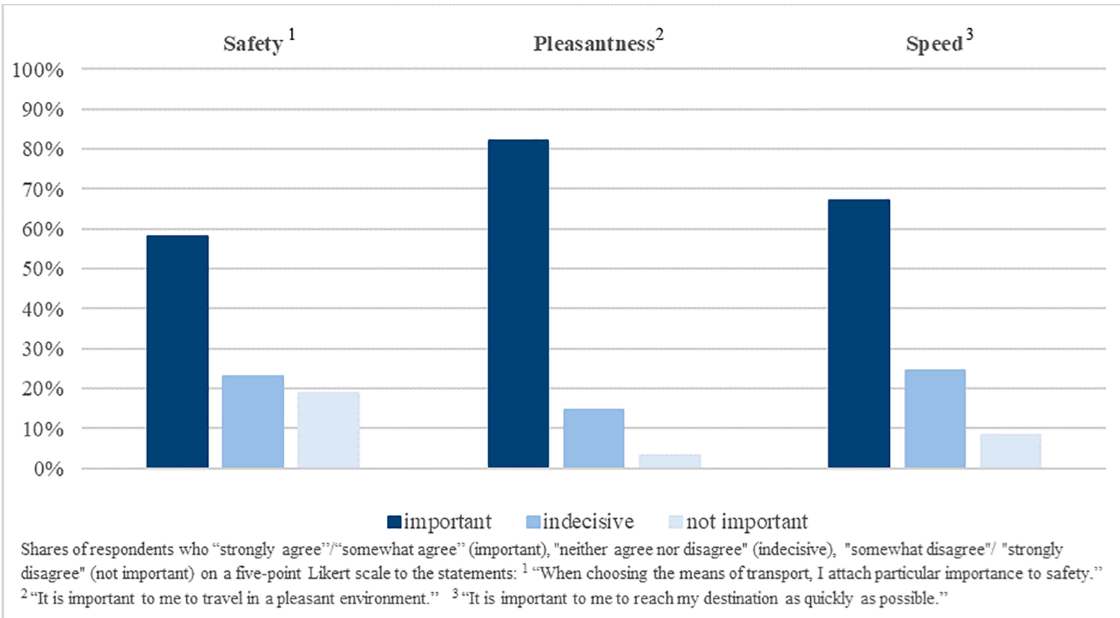

Fig. 4. Descriptive results on the importance of safety, pleasantness and speed when travelling.

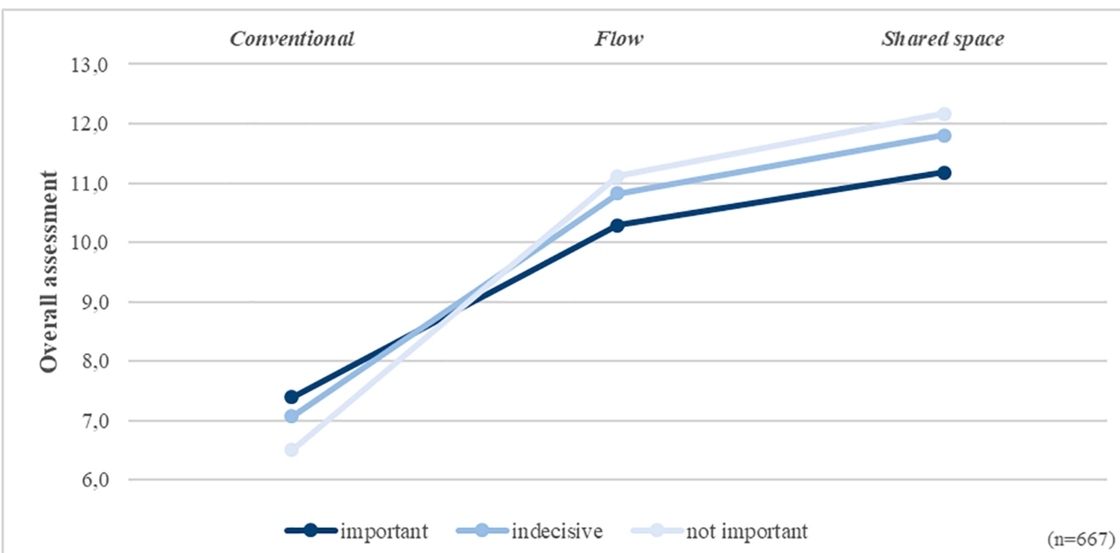

Fig. 5. The association of individual mobility speed preferences and the overall evaluation of the street designs.

like the *shared space* concept more than those for whom speed is important (Fig. 5). Concerning the importance of safety and pleasantness during travel, we could not find any such significant differences in street design assessments.

4.3. Regression analysis of factors influencing the overall assessments of conventional, flow and shared space design

In order to evaluate which respondents favour either *conventional*, *flow* or *shared space* street design, we consider several individual characteristics as independent variables. Besides socio-demographics, mobility preferences and travel mode use, these include individual attitudes regarding different travel modes as well as those related to the general concept of cycle streets. For the latter, we conducted two principal component analyses (PCA). The first one on travel mode attitudes involves 18 Likert-scale items representing statements about travelling by bicycle, car and on foot (Table 2). Based on the eigenvalues and scree plot, the PCA results in three factors. Factor 1 *cycling affinity* describes a positive attitude towards using a bicycle in terms of individual benefits and feasibility. The second factor *car affinity* shows a positive assessment and dependency on car use. Factor 3 *walking affinity* involves positive associations with travel on foot.

The second PCA comprises nine items on the assessment of the cycle street concept resulting in two factors (Table 3). Factor 1 *improving cycling effectively* describes the perception of cycle streets having a positive impact for cyclists and an individual approval for the concept.

Table 2
Factor loading results of the Principal Component Analysis (PCA) regarding travel mode attitudes (n = 701).

Items measured on a five-point Likert scale: (0) "I strongly disagree" - (4) "I strongly agree"	Mean	SD	Factors of travel mode attitudes		
			1 Cycling affinity	2 Car affinity	3 Walking affinity
When riding a bicycle, I am flexible and free.	2.53	1.30	0.853	−0.195	0.016
Riding my bike is fun for me.	2.83	1.29	0.851	−0.001	−0.035
The bicycle is the ideal means of transport for me.	2.13	1.33	0.843	−0.247	−0.063
I am able to reach all relevant everyday destinations by bicycle.	2.10	1.42	0.705	−0.305	−0.007
For me, riding a bike is exhausting and uncomfortable.	1.16	1.20	−0.670	0.047	0.058
I think that cycling is currently popular.	2.75	1.06	0.431	−0.015	0.189
When riding a bicycle, I feel unsafe.	1.73	1.27	−0.335	−0.048	0.135
Travelling by car is fun and a passion of mine.	1.41	1.27	0.005	0.815	0.027
For me the car is the best way to travel.	1.87	1.33	−0.266	0.778	−0.033
When sitting in a car, I feel safe and protected.	2.31	1.10	0.031	0.694	−0.058
I can do my everyday life without a car.	2.67	1.33	0.293	−0.611	0.110
I want to drive a car that is eye-catching.	0.43	0.85	0.012	0.576	0.008
Car traffic is a huge problem for environmental protection.	3.15	1.01	0.334	−0.443	0.218
I like to walk.	3.03	1.00	−0.051	−0.006	0.799
I often walk because there is always something interesting to discover.	2.20	1.19	0.044	−0.057	0.785
Whenever possible, I walk short distances to protect the environment.	3.08	1.12	0.049	−0.073	0.669
Walking is too slow for me.	1.53	1.22	0.237	0.037	−0.662
I admire people who walk whenever possible.	2.58	1.32	0.029	−0.020	0.425
Cronbach's alpha			0.823	0.770	0.698

Principal Component Analysis with varimax rotation; loadings ≤ 0.3 are shown in grey; N = 701; Kaiser–Meyer–Olkin = 0.815; Bartlett's test of sphericity: $\chi2$ = 4528.710 df = 153p =.000; Total variance explained: 50.3%.

Table 3
Factor loading results of the Principal Component Analysis (PCA) regarding cycle street assessments (n = 701).

Items measured on a five-point Likert scale: (0) "I strongly disagree" - (4) "I strongly agree"	Mean	SD	Factors of cycle street assessments	
			1 Improving cycling effectively	2 Hindering car traffic
I think it is a good idea to implement cycle streets in the city of Offenbach.	2.93	1.30	0.886	−0.258
Cycle streets are an important measure to foster bicycle traffic.	3.01	1.13	0.876	−0.125
I like the idea of cycle streets.	3.01	1.25	0.870	−0.251
I am not convinced by the concept of cycle streets.	1.40	1.37	−0.801	0.334
Cycle streets improve the safety of cyclists.	2.92	1.20	0.757	0.049
Cycle streets are a waste of money.	1.16	1.25	−0.740	0.384
I would cycle in cycle streets even though they were not on my direct route.	2.16	1.33	0.705	−0.157
Above all, cycle streets result in detours having to be taken by cars.	2.10	1.19	−0.079	0.857
Cycle streets are obstructive to car traffic.	2.18	1.21	−0.234	0.755
Cronbach's alpha			0.925	0.575

Principal Component Analysis with varimax rotation; loadings ≤ 0.3 are shown in grey; N = 701; Kaiser–Meyer–Olkin = 0.918; Bartlett's test of sphericity: $\chi2$ = 4166.47 df = 26p =.000; Total variance explained: 70.7% (cf. Blitz et al., 2020).

Factor 2 *hindering car traffic* expresses individual concerns about impairments for car traffic due to cycle streets (see Blitz et al., 2020 applying the same PCA).

To examine the relationship between the respondents' individual characteristics and their assessments of the different cycle street designs, we applied three multiple linear regression models (Table 4). Each model refers to one of the three designs, with the sum score of the four Likert scale evaluations of safety, clarity, attractiveness and fun (section 4.1) as dependent variables. All of the calculated models are significant in the prediction of the dependent variables (Cleff, 2019). The models' goodness-of-fit levels (corrected R2) vary between low for models 1 (0.084) and 3 (0.070) and medium for model 2 (0.150) (Cohen et al., 2013).

The results show that certain travel mode attitudes, cycle street assessments and socio-economics contribute to the evaluations of the three cycle street designs. Car affinity positively affects a good evaluation of the *conventional* street design. In contrast, respondents showing cycling or walking affinity tend to favour the *shared space* street design. Assessing cycle streets as improving cycling effectively increases a positive evaluation of all three designs. The perception of cycle streets hindering car traffic is associated with a negative evaluation of *flow* and *shared space* street designs. Regarding the socio-economic characteristics, older respondents and respondents living in a household with their own car tend to poorly assess the *flow* street design. Having a migrant background positively affects *conventional* street design evaluation. No influences can be identified with regard to mobility preferences and regularly used travel modes.

Table 4
Multiple linear regression models for cycle street design evaluations (n = 701).

	Sum score evaluations		
	1 Conventional design	2 Flow design	3 Shared space design
Travel mode attitudes			
Cycling affinity	0.078	0.075	0.154***
Car affinity	0.144***	−0.003	−0.061
Walking affinity	−0.017	0.058	0.095**
Cycle street assessments			
Improving cycling effectively	0.240***	0.256***	0.149***
Hindering car traffic	−0.021	−0.103***	−0.093**
Mobility preferences			
Preferring safety (five-point Likert scale)	0.047	−0.064	−0.027
Preferring speed (five-point Likert scale)	0.045	−0.045	−0.010
Preferring pleasantness (five-point Likert scale)	−0.033	−0.008	−0.020
Regularly used travel modes			
Bicycle (1 = yes; 0 = no)	−0.020	0.013	−0.026
Car (1 = yes; 0 = no)	−0.052	−0.003	0.042
Walking (1 = yes; 0 = no)	0.036	−0.030	−0.015
Socio-economics			
Female (1 = yes; 0 = no)	−0.015	−0.008	0.028
Age	−0.043	−0.156***	0.015
Higher education entrance qualification (1 = yes; 0 = no)	0.031	−0.010	−0.015
Employed/ in education (1 = yes; 0 = no)	−0.020	−0.060	0.034
Monthly net income	−0.061	0.016	−0.023
Migrant background (1 = yes; 0 = no)	0.118***	0.001	0.009
Children in household (1 = yes; 0 = no)	−0.037	−0.014	0.022
Household with car ownership (1 = yes; 0 = no)	0.028	−0.099**	−0.025
R^2	0.109	0.173	0.096
corrected R^2	0.084	0.150	0.070
F-statistic	0.000	0.000	0.000
N	701	701	701

Each column represents one multiple linear regression model; significances: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

5. Discussion

5.1. *Assessments of the cycle street designs in terms of safety, attractiveness and speed*

The results of the analyses provide some relevant insights into the significance of mobility characteristics and associated perceptions of different street designs. First of all, surprisingly, far more participants attribute importance to a pleasant environment and fast travel than to safety. This does not necessarily imply that safety is one of the less important factors of travel behaviour. However, travelling in general may not be seen as very risky and, thus, safety is not of particular importance to everyone (Vredin Johansson et al., 2006). Rather, safety concerns vary by different demographic groups and mode users (Rahman et al., 2021). Additionally, the local environment is not just for traffic. It contributes to the quality of the entire city and its residents' lives. The preference for fast travel may be particularly important on trips covering long distances in order to reduce travel time. In this context, the travel environment plays a key role in ensuring efficient access to destinations.

Among the three cycle street designs, participants evaluate *shared space* as the safest. Bivariate analyses show that the perception of clarity of street structure correlates with safety assessments. This relation is in line with psychological assumptions that clarity and legibility of public spaces enhance individual orientation and the sense of safety (Lynch, 1977; Cai and Wang, 2009). However, since the design assessed to be the clearest in terms of structure (*conventional*) is not the one to be the safest, the results also indicate that the safety evaluation of the designs cannot be explained only by the perception of clarity. Therefore, further characteristics of the *flow* and *shared space* designs seem to determine safety impressions. These include the comparable reduced presence of cars, which is accompanied by a higher presence of pedestrians, cyclists and greenery. Several studies show that high levels of car traffic and parked cars are perceived as safety risks and barriers to active travel, for instance due to speeding, dooring, near collisions and obstructions of view (Hine, 1996; Jacobsen et al., 2009; Chataway et al., 2014; Manton et al., 2016; Kirschner, 2021; Rahman et al., 2021). In contrast, slower velocities and enabled eye contact facilitate communication across the street, which helps to prevent dangerous situations (Frosch et al., 2019). Hence, a lower number of cars may promote safety perceptions. This impression could also be supported by the presence of people indicating a liveable street with social cohesion and mutual consideration (Gehl, 2010; Park and Garcia, 2020). Moreover, the presence of trees in urban spaces has been shown to contribute to safety perceptions (Jansson et al., 2013; Mouratidis, 2019). Therefore, *shared space* involving these characteristics seems to evoke a higher sense of safety than the strict separation of pedestrians seen in the *conventional* street design.

Almost all of the participants assign a high attractiveness to the *shared space* design. This is likely due to the elements contributing to the street's quality of stay. Accordingly, several studies show a positive impact of greenery and water elements in urban space on individual well-being and amenity assessment (Smardon, 1988; Karmanov and Hamel, 2008; White and Gatersleben, 2011). Ulrich (1993) explains this correlation with evolutionary theories, as these elements embody the provision with food and water that is essential for survival (section 2.2). In addition, the higher levels of complexity and mystery expressed by the *flow* and especially by the *shared space* design might contribute to an impression of pleasantness and excitement (Kaplan et al., 1989; Gifford and McCunn, 2019). Thus, the results are in line with the study of D'Acci (2019), who showed that people prefer walking in irregular and curvy streets since these are perceived as more interesting, more dynamic and less monotonous.

As the results indicate, safety and attractiveness are not a contradiction in design. However, this seems to occur when the demand for travel speed is considered (Dumbaugh and Gattis, 2005). Accordingly, the overall assessments of *flow* and *shared space* designs are lower for those respondents who prefer to reach their destinations as quickly as possible. The reason for this may be various characteristics of these designs that impede fast movement. First, the lower level of clarity due to the higher amount of elements in the streetscapes make orientation and wayfinding more difficult (Cai and Wang, 2009; Rybarczyk and Wu, 2014). Second, the presence of people, especially children, indicate the need to be cautious and to be prepared to come to a complete stop at any time. Third, the roadways are not straight and obstacles have to be circumvented. Altogether, travelling fast, especially for cars, is difficult.

5.2. *The impact of individual characteristics on the overall assessments of the cycle street designs*

The regression models show several influencing factors, especially regarding travel mode attitudes and cycle street assessments. Respondents with a high car affinity tend to better evaluate the *conventional* street design. This could be because this design is closest to that of a street with standard regulations and, thus, it might evoke the impression of almost no restrictions for car users. Additionally, the high number of parking spaces addresses car enthusiasts. In contrast, participants showing a higher cycling or walking affinity significantly better evaluate the *shared space* design. A possible explanation for this could be the comparatively more prominent presence of cyclists and pedestrians as well as of infrastructures for these groups, e.g. bicycle parking facilities and benches. Furthermore, the greenery and water elements of this design could be more important to those favouring active mobility. They provide shade and cooling in the urban space and, thus, an appealing microclimate (Chatzidimitriou and Yannas, 2015) to which car users are not exposed that much while driving. Moreover, previous research showed that pedestrians consider irregular and complex street designs as more attractive and interesting (D'Acci, 2019). In addition, the perceptions of safety attributed to the *shared space* design (section 4.1) might be of particular importance to pedestrians and cyclists who are considered vulnerable road users (Yannis et al., 2020). The *flow* design does not seem to address any travel mode affinity in particular. Unlike travel attitudes, individual travel mode use shows no effects on any of the overall assessments. Therefore, the results suggest that attitudes are more important in the evaluation of the street designs than actual habits.

Individual assessments of the cycle street concept also contribute to the overall evaluations of the three designs. Noticeably, perceiving cycle streets as improving cycling effectively, positively affects the assessment of all three designs. In the regression models of c*onventional* and *flow* designs, this factor has the highest odds ratios, indicating that in particular those respondents who associate safe and efficient cycling with cycle streets prefer these two designs. Perceiving cycle streets as hindering car traffic reduces the rating of *flow* and *shared* space designs. This could be due to the visible obstacles hindering fast driving in these two streets.

Only three socio-demographic characteristics contribute to the overall cycle street design assessments. First, people with a migrant background tend to better evaluate the *conventional* design. A reason for this might be the image of the car as an important status symbol in many Eastern European and Asian countries of origin, which is even more distinct than in Western European countries (Haustein et al., 2020). Accordingly, the presence of cars, which is particularly obvious in the *conventional* design, could be associated with high prestige and a wealthy environment, whereas cycling and walking might be stigmatised as lower-class travel modes (Pojani et al., 2017). Moreover, using the car is much more common than cycling for many migrants in Offenbach (Welsch et al., 2018). Second, older participants tend to evaluate *flow* design worse than younger ones. Further analysis showed that the safety assessment of this design differs sharply between different age groups. Since elderly respondents at the same time consider safety to be of high importance, visible obstacles and the presence of cars could have a negative effect on their assessment of *flow* design. Third, owning a car has a negative impact on the overall assessment of the *flow* design. This might be due to the reduced parking areas for cars in favour of greeneries as well as walking and cycling facilities. However, this correlation does not apply to the *shared space* regression model.

5.3. Methodological approach, scope and limitations of this study

The analyses provide new insights into the evaluation of different cycle street designs and related influencing factors. According to the scope of this study, the results may be particularly valuable in the design and planning of cycle street networks in typical dense urban residential areas. However, the rather low regression models' goodness-of-fit values – although still on an acceptable level (Cohen et al., 2013) – indicate that other factors than those included contribute to the assessments of the designs. These may involve individual demands on the local environment unrelated to travel mode use and attitudes, such as preferences for greenery and other aesthetic characteristics, as well as specific trip parameters, for instance distance to be travelled and weather conditions. Additionally, there might be some methodological limitations since the individual assessments of the three designs had to be made using illustrations. It may be difficult to imagine complex scenarios and impressions of the surrounding streetscape based only on one visualisation and one perspective. These involve built and non-built aspects, such as urban materials and sounds as well as human practices and interactions including traffic conflicts. Assessing whether the street evokes feelings of safety or fun might be challenging in particular. Moreover, the respondents may not have the same ideas about these terms. For instance, safety might involve traffic safety, but also safety from crime. Furthermore, it is not clear whether each participant took a closer look at the illustrations, which could have resulted in not everyone considering all of the designs' elements. This may have especially affected the assessments of the *shared space* design, as its specific concept might not have been conveyed by the illustration and, thus, might be interpreted differently. Since parked cars are only shown in the background here, the impression of a car-free area or a pedestrian zone could arise. Possibly, the more largely illustrated elements, i.e. greeneries, cyclists and pedestrians, would then predominate in the assessments. Thus, stated individual design perceptions and evaluations might differ from those experienced in an actual existing street (D'Acci, 2019; Kazemzadeh et al., 2021). Therefore, since the *conventional* cycle street has been implemented in the survey area, it is likely that negative personal experiences, such as traffic conflicts or speeding (Blitz et al., 2020), contributed to the respondents' assessments of this design (Park and Garcia, 2020).

Two additional survey methods seem to be helpful for further research on the perceptions of different cycle street designs. The first would be to observe and interview participants who experienced actual existing streets. Various designs could be implemented as temporary test sections or even permanent constructions. By involving car users, cyclists, pedestrians and residents, the perspectives of different street users could be analysed. A second method could be to visualise the designs by means of virtual reality (VR) technologies. For several years now, it has been possible to create realistic environments in the form of 3D models and corresponding sound effects, allowing 360° perspectives and interactions (Echevarria Sanchez et al., 2017). Thanks to recent developments, it is even possible to have unrestricted cyclist- and pedestrian-like movement in the virtual environments (Kreimeier et al., 2020; Ullmann et al., 2020). Compared to the redesign of an existing street, VR is not as time-consuming and expensive (Wang, 2011), but also allows real-time observation of the participant's experiences and subsequent interviews (Echevarria Sanchez et al., 2017). Moreover, in this way, the research could easily be extended to other urban and rural streets beyond the scope of this study, for instance in commercial and less dense areas.

6. Conclusions

In recent years, cycle streets have become an increasingly popular measure to promote non-motorised traffic in urban areas (Eder, 2017). Even though, in addition to regulations, the design of these streets should contribute to the prioritisation of bicycle traffic, to date there are no standardised design characteristics nor research on individual evaluations of different street designs (Graf, 2018). Therefore, the objective of this paper was to analyse the assessments of safety, clarity, attractiveness and fun of three different cycle street designs in an inner-city residential area: *conventional*, *flow* and *shared space*. For this purpose, visualisations of the designs were implemented in a written household survey we conducted in two neighbourhoods of the German city Offenbach am Main (n = 701).

The results show that the respondents assess the *shared space* design to be best overall, whereas the *conventional* design is rated the worst. Safety, attractiveness and fun are evaluated the highest for *shared space*. Those with positive attitudes towards cycling and walking especially favour this design. While safety and attractiveness can be combined in this design, the demand for fast travel rather counteracts a good assessment of *shared space* (Dumbaugh and Gattis, 2005). Thus, planning needs to consider what the design aims to achieve in a particular street depending on its context. While in streets with a high percentage of pedestrian traffic, safety and attractiveness should be the focus; in cycle streets that are part of an urban cycling network covering long distances, more attention could be paid to design for efficient cycling. For the latter, the *flow* design seems to be suitable, as it provides separation of travel modes and clarity, just like the *conventional* design, but at the same time is assessed as much safer and more attractive. Elements, such as bicycle parking, greenery, more noticeable dooring zone markings and fewer car parking spaces, contribute to this evaluation. Using similar and additional elements, the *shared space* design invites street users to linger. The street's function as a traffic area thus becomes secondary.

The findings of this study give new insights into the assessments of cycle streets for future planning and construction. Selecting a typical urban residential street makes the results transferable to other cycle streets in a comparable spatial context. However, the participants' assessments are based on illustrations and not on actual experiences. Therefore, additional research could focus on specific design elements and further aspects of the streetscape, such as urban materials and human practices, by investigating impressions of actually implemented cycle streets or by involving VR technologies. Moreover, a closer look at non-residential functional areas of the city could provide further insights. For instance, it seems appropriate that cycle streets at destinations of high frequency, such as shopping opportunities, public transport hubs and workplaces, should foremost provide good accessibility and bicycle parking facilities. Whereas, with regard to certain recreational destinations, e.g. parks and cafes, cycle streets with a high amenity quality appear more suitable. In streets accessing schools or retirement homes, design should take into account special safety needs. Less densely developed areas with wide streets and few residents could allow more space for bicycle traffic. Here, separate bike lanes might be a good alternative, especially if there is a lot of car traffic, while shared space designs are unlikely to be suitable. Along with designing cycle streets appropriately for their purposes, they should be planned in conjunction with other bicycle infrastructures to create a safe, attractive, convenient and identifiable network on a citywide scale (Schröder, 2021). In this way, important destinations should be made accessible to encourage frequent cycling.

CRediT authorship contribution statement

Hannah Müggenburg: Conceptualization, Methodology, Formal analysis, Writing – original draft, Project administration. **Andreas Blitz:** Conceptualization, Investigation, Formal analysis, Data curation, Writing – original draft, Writing – review & editing. **Martin Lanzendorf:** Conceptualization, Writing – review & editing, Supervision, Project administration, Funding acquisition.

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.

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