

# En-route weather and place valuations for different transport mode users



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## ABSTRACT

With the increasing societal interest in climate change, mostly separated strands of literature have investigated the travel-behavioural, thermo-sensational and environmental-psychological effects of weather on people in everyday life. This research conceptually and statistically integrates these fragmented insights. Drawing on unique Greater Rotterdam (The Netherlands) travel diary data enriched with hourly meteorological and spatial route attributes, we analyse how weather affects different transport mode users' en-route place valuations in terms of liveliness, friendliness and aesthetics. Our main findings indicate that windy, cloudy, cold ( $<15^{\circ}\text{C}$ ) or too hot ( $\geq 25^{\circ}\text{C}$ ) weather conditions negatively affect en-route place valuations, either directly or through lower thermal comfort. Active mode users generally value their route surroundings more positively than motorised transport modes, however they also appear more strongly affected by weather in their thermal experiences and place valuations. Policy makers are advised to expand climate-sensitive urban planning along active transport mode infrastructures.

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## 1. Introduction

With climate change high on the political agenda, weather and climate have emerged as important topics in travel behavioural research and transport planning. On the one hand, transport forms an important contributor to climate change through greenhouse gas emissions (e.g. Chapman, 2007). On the other hand, as of its direct exposure to weather, the transport sector is also highly affected by climate change (e.g. Koetse and Rietveld, 2009). In this light, various studies investigated the effects of weather on daily travel behaviours, including choices for active and motorised transport modes, destinations and travel distances (for detailed reviews see Koetse and Rietveld, 2009; Böcker et al., 2013). While most of these studies focus on objective weather and behaviour, much less is known on how weather is subjectively experienced and how it affects the experience of place during travel. Exactly this knowledge, on subjective experiences of weather and place during travel, is crucial to better understand transport mode decisions and to support *climate-sensitive urban planning* (Eliasson et al., 2007; Lenzhölder and Wulp, 2010) – especially with regard to

the facilitation of infrastructures for healthy and sustainable, but weather-exposed, active transport modes.

The relationships between weather, travel and subjective experiences of weather and place, have been addressed in three separated strands of literature. First, transport scientists have investigated the *travel-behavioural effects* of objectively measured weather conditions on transport mode choices. Studies generally conclude that cold, cloudy, wet and windy weather conditions stimulate motorised transport, while warm, sunny and dry weather conditions increase usage of active modes – with typically larger effects for leisure than for utilitarian trips (e.g. Hanson and Hanson, 1977; Sabir, 2011; Creemers et al., 2014). Regarding temperature, some studies added that not only cold, but also hot weather above optimums between 25 and 30 °C may negatively affect walking (Aultman-Hall et al., 2009) and cycling (e.g. Ahmed et al., 2012; Lewin, 2011; Miranda-Moreno and Nosal, 2011).

A second set of, mostly biometeorological, studies have investigated the *thermo-sensational effects* of objectively observed weather conditions on subjective weather experiences. It is indicated that we experience thermal (dis)comfort as a combination of different meteorological variables, including air temperature, wind speed, humidity and solar radiation. However, studies also observe considerable discrepancies between measured and subjectively experienced weather (e.g. Nikolopoulou and Steemers,

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2003), which could be related to personal or cultural backgrounds (e.g. Knez and Thorsson, 2006; Thorsson et al., 2007), clothing and physical activity levels (e.g. Havenith et al., 2002) or site-specific spatial configurations. Green, shadowed and/or wind-exposed environments are generally perceived as colder than concrete, sunlit and/or wind-sheltered environments (e.g. Nikolopoulou and Lykoudis, 2007; Phung and Rose, 2008; Lenzhölder and Wulp, 2010).

A third, but very limited, selection of studies investigates the *environmental–psychological effects* of weather on place perception and valuation. From a philosophical viewpoint Yurike Saito (2005:160) explores the multisensory effects of weather on aesthetic experiences of everyday environments: “Our experience of a fierce autumn wind is not simply the feeling of wind against our body; the way in which fallen leaves swirl around, the dynamic swaying of tree branches, the rustling sound they make, the slightly musty smell coming from half-decaying leaves accumulated on the ground, and the rapid movement of clouds all contribute toward our experience of this windy weather”. Within the fields of biometeorology and climate-sensitive urban design, some quantitative studies also investigated the role of weather or seasonality on experiencing aesthetics in outdoor urban public spaces. Mambretti (2011) finds that two urban parks in Zurich, Switzerland, are experienced as more beautiful during spring and autumn, compared to summer and winter. Two studies from Gothenburg, Sweden, link aesthetics directly to weather. Eliasson et al. (2007) conclude that urban parks are experienced as more beautiful with higher air temperatures and lower wind speeds, while Knez et al. (2009) find no significant effects of weather conditions on aesthetic experiences. Apart from aesthetics, also social aspects of place valuation (Cattel et al., 2008) may be affected by weather. Pleasant mild to warm, sunny, dry and calm weather conditions may enhance social interactions, liveliness, friendliness and safety in outdoor public space, as these conditions increase the outdoor presence of people (e.g. Zacharias et al., 2001; Thorsson et al., 2007; Lin, 2009) and positively affect emotions (Köös et al., 2011).

So far, despite recent calls for a more interdisciplinary approach (Eliasson et al., 2007; Böcker et al., 2013), insights into the interdependencies between the above-outlined three strands of literature are lacking. It is this paper's aim to integrate these separated insights both conceptually and statistically. This way we examine how weather experiences, mode choices and en-route place valuations influence and compensate each other. We analyse the direct and mediated (by thermal comfort) effects of hourly air temperature, precipitation sum, wind speed and sky clearness on different transport mode users' en-route place valuations in terms of liveliness, friendliness and aesthetics, while controlling for various personal, trip, temporal and spatial attributes (i.e. address density, building diversity, percentage green). Hereto, we analyse unique travel diary data from a panel study amongst 945 Greater Rotterdam respondents (The Netherlands), enriched with spatial and meteorological data, by means of Structural Equation Models. The paper first describes the study area and methods used. The results section describes and explains the model outcomes. A concluding section summarizes and discusses the main findings and draws implications for future research and policy regarding the role of climate-sensitive urban planning.

## 2. Research design

### 2.1. Study area and data

This study is situated in Greater Rotterdam, the Netherlands (Fig. 1). This coastal harbour region is part of the Randstad

conurbation: the densely populated and economically vital metropolitan region, which in addition to Rotterdam contains the cities of Amsterdam, The Hague, and Utrecht. The region has a maritime climate, characterised by mild winters (lows: 1 °C; highs: 6 °C), warm summers (lows: 12 °C; highs: 21 °C), and relatively stable seasonal precipitation patterns (ranging from 158 mm in spring to 258 mm in autumn) (KNMI, 2013). Greater Rotterdam was selected for this study because of three reasons: First, the area consists of a large variety of spatial environments, ranging from largely post-WWII mid- and high-rise inner-city areas, to compact historic towns and newer lower-density satellite towns and villages in the outskirts. Second, the area has rich population diversity in terms of age, ethnicity and socio-economic status. Third, the region pursues active policy on sustainable transport and climate-sensitive urban planning.

We conducted a travel diary survey (used in two earlier studies: Böcker and Thorsson, 2014; Helbich et al., 2014) from August 2012 to February 2013 amongst a panel of 945 respondents, aged 18 and older, from different Greater Rotterdam residential environments (Fig. 1). The reason for using panel data is to have the same sample of respondents participating in travel surveys during different seasons throughout the year. Hereto, respondents were randomly assigned two regular<sup>1</sup> days in summer, two days in autumn and two days in winter, to report their travel behaviours and experiences. Following Moskowitz and Young (2006) an ecological momentary assessment (EMA)<sup>2</sup> methodology was used. Respondents report on a trip basis repeated measurements of weather perceptions and en-route place valuations in on site travel diaries, which can thus directly be linked to reported trip mobility data. In our sample we oversampled for non-native Dutch and older age groups (>65 years) in anticipation of lower response rates for these groups. Our sample represents the Greater Rotterdam population relatively well on several key socio-demographic statistics like age, gender and household size (CBS, 2013), except for an underrepresentation of lower educated and non-western<sup>3</sup> people (for more information on the sample composition, see Böcker and Thorsson, 2014).

Next, the travel survey data are enriched with spatial route attributes. Hereto, trip origin and destination addresses are geo-coded via Dutch cadastral data (2014) on a 6-digit postal code level, containing roughly 17 addresses per spatial unit. Utilizing a geographic information system (GIS) and 2008-street data provided by ESRI, origins and destinations are linked along the street network using shortest-path analysis. Following Schlossberg et al. (2006), each trip path has been buffered with a radius of 200 m. This 200 m buffer is large enough to capture the area had people taken slightly different routes, while it is small enough to capture mostly the nearby surroundings in a direct line of sight that are most relevant to the traveller. Subsequently, route specific attributes describing the traversed environments are extracted. Hereto, each trip buffer is intersected with a grid having a spatial resolution of 100 m superimposed on the study area. This spatial scale keeps GIS computation time modest, while details about local urban form elements remain preserved (e.g., open spaces). For each cell three indicators are extracted: building usage diversity, address density, and greenness index. Building usage diversity and address density are extracted from the 2014-dataset ‘Basisregistraties, Adressen en Gebouwen (BAG)’. Greenness is extracted from the 2001-dataset ‘Landelijk Grondgebruiksbestand

<sup>1</sup> Regular days contain both weekdays and weekends, but exclude periods in which the respondent was ill or on holiday, in which case new days were assigned.

<sup>2</sup> Ecological momentary assessment (EMA) is the repeated sampling of respondents' behaviours and experiences in real time and on-site, in contrast to for instance the retrospective sampling (at home) in a survey.

<sup>3</sup> Respondents who, or whose parents, were born in a non-western country.

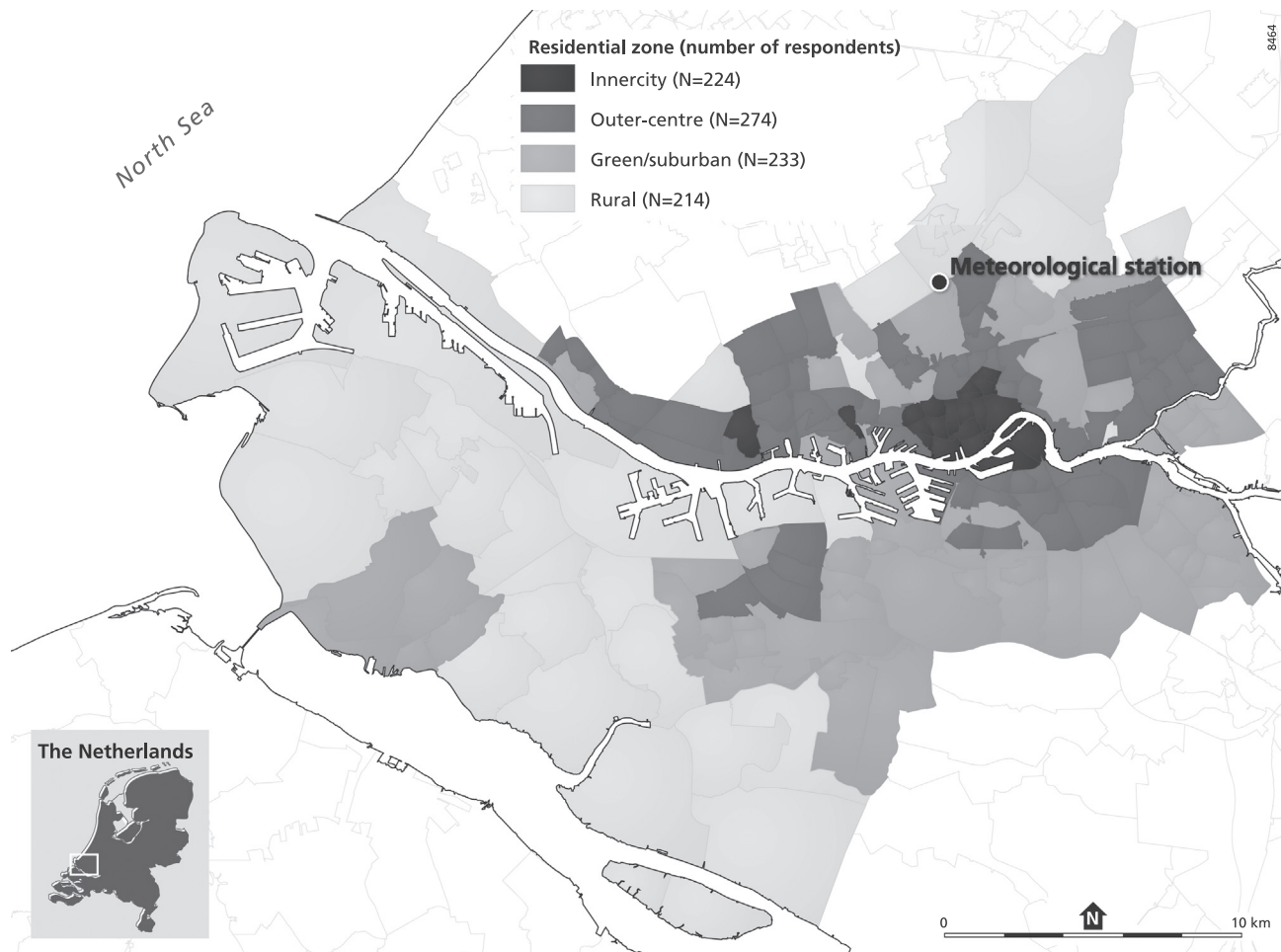


Fig. 1. Greater Rotterdam study area. Source: Böcker and Thorsson (2014). Administrative level: 4-digit postal codes.

Nederland (LGN). The building usage diversity refers to the mix of building usages (i.e. office, shop, public service, etc.) and is operationalized based on the Shannon index. A Shannon index value of 0 refers to a cell with only one building usage while higher values represent cells in which building usages are more diverse. Address density refers to number addresses (residential and non-residential) per cell. Greenness index refers to the surface-area proportion of green space.

Finally, the travel survey data are linked to hourly meteorological records obtained from a Royal Dutch Meteorological Institute measurement station (KNMI, 2013) located inside the study area, just north of Rotterdam (Fig. 1). We include in our analysis the effects of hourly average wind speed (in m/s), precipitation sum (in mm) and air temperature (in °C) – the three most commonly used meteorological variables in existing studies (e.g. Böcker et al., 2013). Additionally, we analyse the effect of the hourly sky clearness index: the ratio between the observed and the theoretical maximum incoming solar radiation given the specific time and location on the earth's surface (Crawford and Duchon, 1999). High values (closer to 1) represent clear sky conditions, while lower values (closer to 0) represent cloudier weather. We reclassified sky clearness into dummies to distinguish between 0 values indicating darkness and non-zero values indicating various degrees of cloudy to clear skies. Finally, we control for whether or not snow-cover has been accumulated on the ground, as this may have direct effects on travel activities as well as place valuations. Our August 2012 to February 2013 study period featured a great variety

of weather conditions: (1) sunny warmer-than-average weather late August (with a peak of 34 °C), early September and late October; (2) mild but very wet weather in December; (3) snow, ice and sub-zero daily maximums by mid-January. See Böcker and Thorsson (2014) for a more detailed description.

## 2.2. Multivariate modelling techniques

One of our ambitions in this paper is to statistically integrate the behavioural, thermo-sensational and environmental-psychological mechanisms when mediating the effects of weather on en-route place valuations. To integrate these three mechanisms into one analysis, use is made of Structural Equation Modelling (SEM), via the software package Mplus. The rationale for using SEM is twofold. First, a major statistical challenge is that, apart from a large set of independent personal, spatiotemporal and weather variables, we have not one, but three interrelated dependent variables: main transport mode choice, perceived temperature, and en-route place valuation. Unlike regular regression techniques, SEM allows for multiple dependent variables in one model and also accommodates mediating mechanisms that connect the three interrelated dependent variables. Second, within SEM we can specify in a *factor model* our final dependent variable 'en-route place valuation' as a latent construct based on three underlying items, treated as ordinal variables, covering both physical and social appeals of place: aesthetics, liveliness and friendliness. Hereto we asked respondents to respond on 5-point Likert

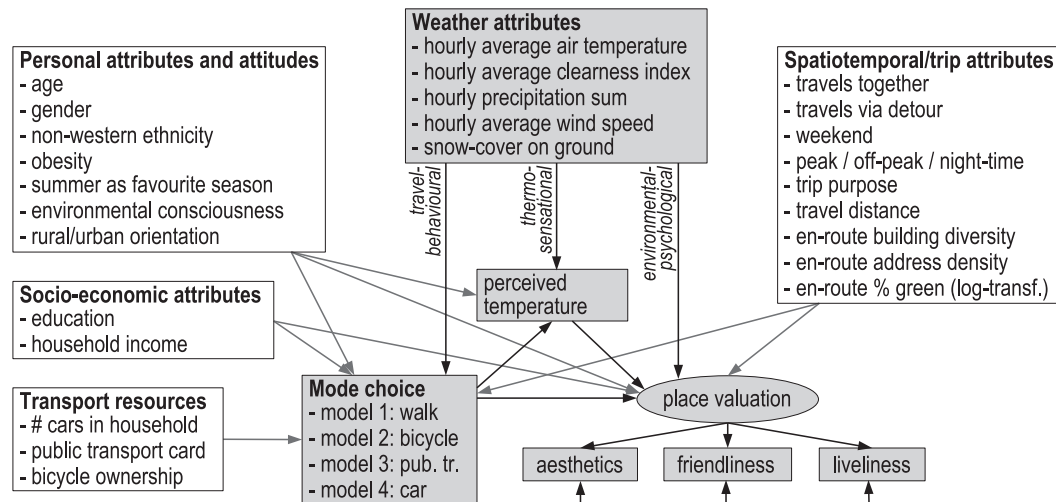


Fig. 2. SEM conceptual model.

scales to the following statements: “I predominantly perceive my travel surroundings as: *beautiful*-5-4-3-2-1-*ugly*; *lively*-5-4-3-2-1-*boring/monotonous*; *friendly atmosphere*-5-4-3-2-1-*distant atmosphere*.” We based this factor model on a principal component analysis run in advance, which revealed the one-factor solution in which all three items are positively loading.

In the regression part of the SEM we analyse the effects of directly-measured *personal* (age, gender, ethnicity), *attitude* (favourite season, environmental consciousness,<sup>4</sup> urban/rural orientation,<sup>5</sup>) *socio-economic* (education, net household income), *transport resource* (number of cars in the household, type of bicycle owned), *spatiotemporal* (week/weekend, peak/off-peak/night-time, and the earlier discussed spatial attributes), *trip* (distance, purpose, detouring, travel companion) and *weather* variables on mode choice, perceived temperature and en-route place valuation, as well as the relationships between the three dependent variables. Not all dependent variables are regressed on all independent variables. Personal and attitude variables may theoretically affect all three dependent variables, but other effects, such as that of socio-economic variables or transport resources on thermal perceptions, are less logical and have therefore been excluded.

Causality between the three dependent variables is conceptualised theoretically. Perceived temperatures and en-route place valuations during the trip are treated as consequences of the mode choice decision made in advance. En-route place valuations are analysed as a consequence of perceived temperatures, because biometeorological research indicates the importance of the thermal environment in general comfort levels (e.g. Thorsson et al., 2007; Knez et al., 2009) and place assessment (Eliasson et al., 2007). Based on these theoretical causalities, en-route place valuation is our final dependent variable, while transport mode choice and perceived temperature are mediators. This results in the SEM conceptual model depicted in Fig. 2. Because it proved challenging to include transport mode choice as one multinomial mediator in SEM, four separate models were estimated, each of which includes one transport mode as a binary mediator.

In our hierarchically structured travel diary panel data, trips are nested within day-records, which on their turn are nested within

respondents. As a consequence, we have to deal with the issue of non-independent observations. To account for this issue, in the software package Mplus we have estimated robust standard errors for all observations clustered within one respondent, via a Huber–White procedure that assumes independence only amongst cluster units and not amongst individual units (see Muthén and Satorra, 1995 for more information).

### 3. Results

#### 3.1. Descriptive results

First, we will explore how people's subjective en-route place valuations are related to objective spatial route characteristics (Fig. 3). It appears that green route environments are valued higher in terms of aesthetics. This is congruent with studies indicating the direct aesthetic qualities of urban parks and green spaces (e.g. Sheppard and Harshaw, 2002; Smardon, 1998). Although less pronounced than with aesthetics, greener routes are also experienced as friendlier. A reason could be that green areas invite active mode users to socially interact (Hansmann et al., 2007; Korpela et al., 2014). The relationship between greenness and liveliness is less clear: green areas and areas with a lack of green are experienced equally lively. In contrast to green areas, routes with higher address densities and building diversities – are perceived as less aesthetic. These reduced aesthetics could be related to a lack of green space in urban environments, but may also be related to the lack of aesthetically attractive historic inner-city areas in Rotterdam, due to major Second World War bombings. On the plus side, denser and more diversely built environments are valued higher in terms of liveliness, possibly thanks to more people (Carmona et al., 2003; Cattel et al., 2008), objects, sounds and smells in busy urban environments. These more diverse and densely built environments are valued as slightly less friendly, which could be related to a faster and/or more individualised life in the city compared to the countryside.

Fig. 4 indicates the effects of hourly weather conditions on en-route place valuations. Overall, aesthetics are valued lower than liveliness and friendliness. Nevertheless, when considering the slopes of the graphs, it appears that weather conditions have a relatively similar effect on all three items of place valuation. Overall, people's en-route place valuations increase with higher hourly air temperatures and sky clearness, and decrease with precipitation and wind speeds above 4 m/s. The observed positive effect of air

<sup>4</sup> To what extent a respondent is overall environmentally conscious in his/her daily life (e.g. regarding saving energy, recycling, consumption, travel), measured on one 5-point Likert scale as an ordinal variable.

<sup>5</sup> To what extent a respondent is urban- (values street-life/shops/amusements of the city) or rural-oriented (values natural amenities) measured on a two-sided 5-point Likert scale as an ordinal variable (following Knez, 2005).



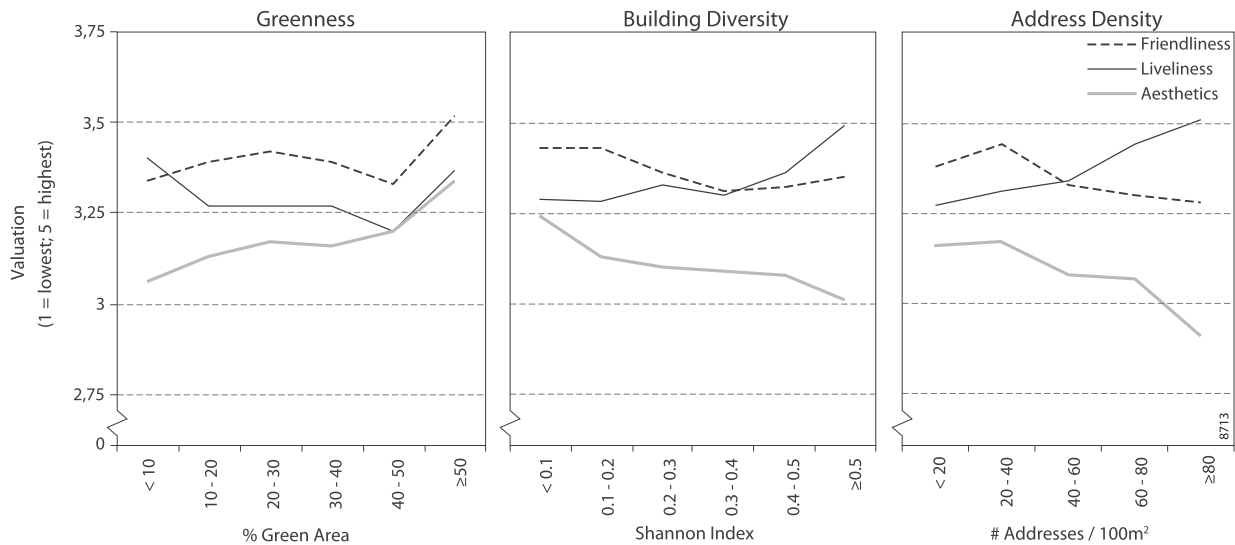


Fig. 3. Valuation of different route environments.

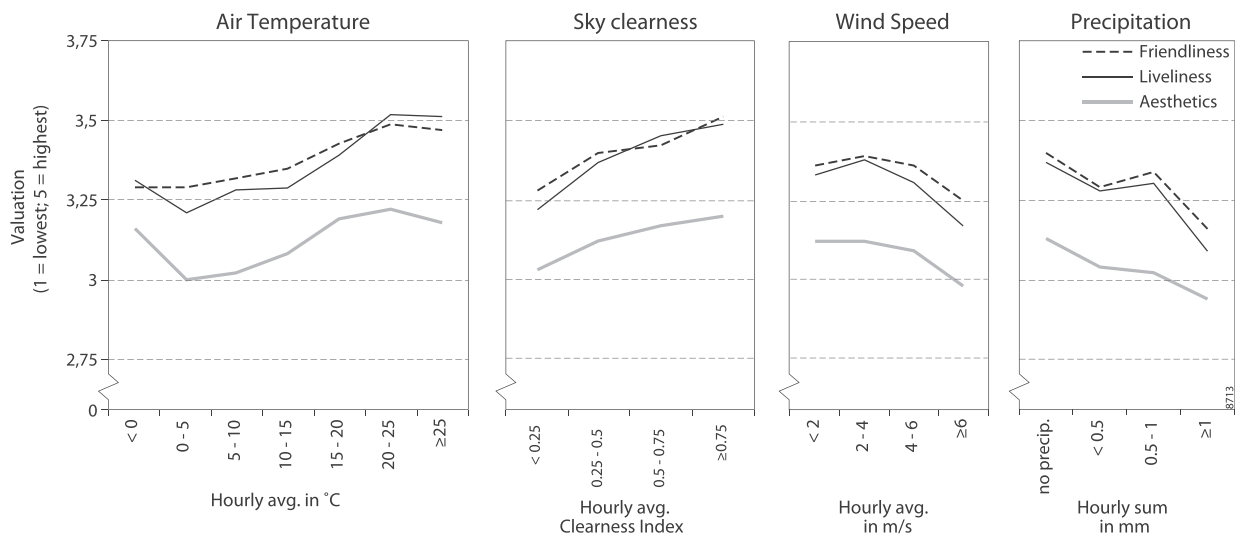


Fig. 4. Weather and en-route place valuation.

temperature and negative effect of wind speed on experienced aesthetics are congruent with Eliasson et al., 2007. Weather effects on experienced liveliness have not been studied before, but could be explained from increased outdoor presence of people during warm, dry, calm and sunny weather conditions (e.g. Zacharias et al., 2001; Thorsson et al., 2007; Lin, 2009). The effects of weather on en-route experiences could also be mediated by people's emotional states (Knez et al., 2009). From another study we know that dry, sunny, calm and warm but not too hot weather leads to more positive emotions during travel (Böcker et al., 2014). These positive emotions may make spatial surroundings look more beautiful, and may also result in more and more-pleasant social interactions with travel companions or strangers and, hence, higher valuations of liveliness and friendliness. Regarding air temperature, Fig. 4 demonstrates that valuations of place aesthetics, friendliness and liveliness, are relatively positive during sub-zero temperatures, while flattening out or even turning negative above 25 °C. The first could be related to the long period of cold, but attractive sunny and snow-covered winter weather mid to late January 2013. The latter could indicate a potential negative effect of heat on comfort levels (e.g. Zacharias et al., 2001; Nikolopoulou and Lykoudis, 2007; Lin,

2009), which may mediate en-route place valuations (e.g. Eliasson et al., 2007; Knez et al., 2009).

### 3.2. Multivariate results

Table 1 presents four full-sample structural equation models, which are identical except that each contains another dependent variable for mode choice. The four models contain three columns, which present the standardized coefficients and their significance levels for the three dependent variables mode choice, perceived temperature (Tfeel), and en-route place valuations (Place-v). The factor model indicates that all items load positively on en-route place valuations. Specified according to the arrows in Fig. 2, the regression model contains the effects of weather along with other independent variables on the three dependent variables, as well as the mediating effects between the dependent variables: perceived temperature on en-route place valuations; and mode choice on perceived temperature and en-route place valuations. All models fitted well, with Root Mean Square Error of Approximation (RMSEA) values well below the critical level of 0.05 and Comparative Fit Index (CFI) and Tucker Lewis Index (TLI) values around or above 0.95.

**Table 1**  
Full-sample structural equation models for the different transport modes.

SEM: Standardized coefficients: estimator = WLSMV <sup>a</sup> , cluster = respondent-id <sup>b</sup> , N = 11,759 trips												
	Model 1: Walking			Model 2: Cycling			Model 3: Public transport			Model 4: Car		
	Walk	Tfeel	Place-v	Bicycle	Tfeel	Place-v	Pub. tr.	Tfeel	Place-v	Car	Tfeel	Place-v
<i>Factor model</i>												
Aesthetics	–	–	.719	–	–	.723	–	–	.721	–	–	.723
Friendliness	–	–	.676***	–	–	.668***	–	–	.671***	–	–	.675***
Liveliness	–	–	.550***	–	–	.555***	–	–	.554***	–	–	.550***
<i>Regression model</i>												
<i>Personal &amp; attitudes</i>												
Age	.071***	–.021	–.043	–.114***	–.028**	–.018	–.067	–.020	–.034	.064**	–.024*	–.017
Male (ref = female)	–.037*	.035***	–.002	–.069*	.032**	–.001	.058	.035***	–.005	.079***	.033**	.008
Nonwestern ethn. (ref = western)	.005	–.007	.011	–.073**	–.010	.020	.069**	–.008	.015	.018	–.007	.016
Obese (ref = not obese)	–.062***	.007	–.031	–.057*	.005	–.036	.007	.008	–.042	.106***	.004	–.020
Summer as favourite (ref = other)	.019	–.022*	–.029	–.014	–.023*	–.024	–.005	–.022*	–.026	.017	–.023*	–.021
Environmental consciousness	.028	–.005	.043	.094***	–.001	.038	–.019	–.005	.047*	–.095***	–.002	.028
Rural-orientated	–.026	.017	–.029	.074**	.021*	–.042	–.039	.018	–.036	–.014	.018	–.036
<i>Socio-economic</i>												
Education middle (ref = lower)	–.026	–	–.065	.008	–	–.070*	.004	–	–.069*	.034	–	–.062
Education higher (ref = lower)	.019	–	–.087**	–.036	–	–.080*	–.087*	–	–.087**	.056	–	–.072*
HH-income €3–4K (ref < €3K)	–.015	–	.036	–.042	–	.037	.010	–	.034	.032	–	.039
HH-income €3–4K (ref < €3K)	–.017	–	.043	.010	–	.039	–.037	–	.038	.003	–	.040
HH-income unknown (ref < €3K)	–.029	–	.045	–.011	–	.042	.045	–	.043	.007	–	.042
<i>Transp. resources</i>												
Number of cars in household	–.043**	–	–	–.127***	–	–	–.258***	–	–	.261***	–	–
Pub-transp. card (ref = no card)	–.001	–	–	.053*	–	–	.248***	–	–	–.177***	–	–
City bike (ref = no bike)	–.029	–	–	.294***	–	–	.025	–	–	–.124**	–	–
Sports/e-bike (ref = no bike)	–.029	–	–	.350***	–	–	–.075	–	–	–.148***	–	–
<i>Trip attributes</i>												
Travels together (ref = alone)	.012	–	.032	–.198***	–	.054**	.034	–	.036	.151***	–	.065***
Travels via detour (ref = direct)	.051***	–	.073***	.030**	–	.079***	–.016	–	.081***	–.079***	–	.066***
Weekend (ref = weekday)	.017	–	–.041	–.002	–	–.038	–.079**	–	–.042	.022	–	–.033
Peak hour (ref = off-peak)	.005	–	.009	.014	–	.008	.043*	–	.012	–.027*	–	.004
0:00–5:59 h (ref = 6:00–23:59 h)	.004	–	–.038**	.032**	–	–.040**	–.006	–	–.037***	–.025**	–	–.042***
Trip for work/study (ref = leisure)	–.201***	–	–.152**	.017	–	–.188***	.147**	–	–.180***	.126**	–	–.161***
Trip for errands (ref = leisure)	–.078***	–	–.059**	.014	–	–.074***	–.137***	–	–.079***	.121**	–	–.047***
Trip for social (ref = leisure)	–.082***	–	–.071***	.018	–	–.087***	–.063**	–	–.088***	.118***	–	–.060***
Travel distance in km	–.717***	–	.086**	–.391***	–	.001	.168***	–	–.032**	.220***	–	.005
<i>En-route trip environment</i>												
Building diversity Shannon index	.019	–	–.035	–.005	–	–.031	–.018	–	–.033	–.006	–	–.033
Address density	.068***	–	–.011	.000	–	.001	.043	–	.003	–.134***	–	–.027
Green %, log-transformed	–.025	–	.028	.059**	–	.017	–.130***	–	.017	.025	–	.028
<i>Hourly weather</i>												
Ta > 25 °C (ref = >20–≤25 °C)	.017	.144***	–.033*	–.005	.144***	–.031*	–.014	.144***	–.031*	–.003	.144***	–.033*
Ta > 15–≤20 °C (ref = >20–≤25 °C)	.025	–.298***	–.025	–.026	–.299***	–.016	.076***	–.300***	–.018	–.030*	–.297***	–.023
Ta > 10–≤15 °C (ref = >20–≤25 °C)	.031*	–.493***	–.064*	–.062**	–.496***	–.049*	.050*	–.495***	–.057**	–.002	–.494***	–.053*
Ta > 5–≤10 °C (ref = >20–≤25 °C)	.031*	–.691***	–.081**	–.072***	–.694***	–.063*	.071**	–.693***	–.073**	–.008	–.691***	–.068**
Ta > 0–≤5 °C (ref = >20–≤25 °C)	.002	–.557***	–.070*	–.064**	–.560***	–.058*	.009	–.557***	–.070*	.040*	–.559***	–.053*
Ta ≤ 0 °C (ref = >20–≤25 °C)	.035	–.672***	–.039	–.025	–.673***	–.024	.033	–.673***	–.031	–.016	–.672***	–.027
Psum in mm	.010	–.014*	–.039**	–.031*	–.016**	–.034**	.030**	–.015**	–.036***	.000	–.014**	–.037***
Ws in m/s	–.020	–.071***	–.020	–.014	–.072***	–.022	.034	–.072***	–.022	.026	–.072***	–.017
Snowcover (ref = no snowcover)	.022	.000	.034	–.065	–.003	.045	.039	–.001	.040	.001	.000	.038
CI ≥ .5–<.75 (ref: CI > .75)	.004	–.026***	–.024	.024	–.025**	–.026	.047**	–.027***	–.021	–.026	–.025***	–.028

(continued on next page)

Table 1 (continued)

SEM: Standardized coefficients: estimator = WLSMV <sup>a</sup> , cluster = respondent-id <sup>b</sup> , N = 11,759 trips												
	Model 1: Walking			Model 2: Cycling			Model 3: Public transport			Model 4: Car		
	Walk	Tfeel	Place-v	Bicycle	Tfeel	Place-v	Pub. tr.	Tfeel	Place-v	Car	Tfeel	Place-v
CI ≥ .25–<.5 (ref: CI > .75)	.021	–.050***	–.039*	–.010	–.051***	–.034	.041	–.052***	–.033	–.009	–.050***	–.036*
CI < .25 (ref: CI > .75)	.025	–.045***	–.038	–.006	–.046***	–.033	.012	–.046***	–.033	–.013	–.045***	–.036
CI = darkness (ref: CI > .75)	.002	–.059***	–.139***	–.067**	–.062***	–.131***	.020	–.059***	–.138***	.062**	–.061***	–.124***
<i>Mediators</i>												
Indicated mode (ref = other mode) <sup>c</sup>	–	–.015**	.177***	–	–.049***	.105***	–	.025*	–.048	–	.038***	–.208***
Perceived temperature (Tfeel)	–	–	.061*	–	–	.069**	–	–	.060*	–	–	.074**
<i>Model quality</i>												
Dep. var. R <sup>2</sup>	.646	.692	.113	.349	.693	.109	.385	.692	.104	.381	.692	.133
Model Chi <sup>2</sup> (df.)												
286.799(130)***												
289.150(130)***												
270.867(130)***												
298.347(130)***												
RMSEA/CFI/TLI	.013/ .972/ .947			.012/ .974/ .949			.012/ .973/ .948			.013/ .970/ .941		

<sup>a</sup> Estimator is Weighted Least Squares Means and Variance adjusted.

<sup>b</sup> Standard errors have been adjusted for respondent clusters indicated by a unique respondent-id.

<sup>c</sup> Mediator is the indicated transport mode in reference to other transport modes: For instance walk (ref = no walking) in walking model, cycle (ref = no cycling) in cycling model, etc.

\* Significance level:  $p < .1$ .

\*\* Significance level:  $p < .05$ .

\*\*\* Significance level:  $p < .01$ .

### 3.2.1. Mode choices

Indicated by the  $R^2$  values, the models specified in Table 1 explain transport mode choices relatively well<sup>6</sup>: 65% of the variance in walking, 35% in cycling, 39% in public transport and 38% in car usage. Before we turn to the effects of weather on mode choices, the effects of other independent variables will be briefly summarised. According to our expectation and in line with the literature (e.g. Seskin and Cervero, 1996; Dieleman et al., 2002; Bühler, 2011), the most important predictors of transport mode choices are transport resources, trip distance, trip purpose, and whether people are travelling alone or in company. The number of cars in the household increases car usage; public transport card membership increases public transport usage and cycling; and bicycle ownership (particularly of sports or electric bikes) increases cycling over car usage. Short-distance trips are more often performed by active modes; long distance trips more often by motorised modes. Regarding trip purposes, leisure trips have a relatively high share of walking and a relatively low share of car usage; work trips a relatively high share of motorised modes. Compared to car users, cyclists are more likely to travel alone.

Other background characteristics, such as socio-demographics and spatiotemporal trip environments have a smaller impact on mode choices. Nevertheless some significant effects can be identified: Non-western immigrants cycle less; older people cycle less and travel more by foot and by car; and men and obese people are more likely to travel by car instead of active transport modes. In addition to classic socio-demographic factors, we also included in our models the effects of personal attitudes: environmentally conscious people cycle more often and make less use of the car; rural-oriented people are more likely to cycle. Regarding trip environments, congruent with Seskin and Cervero (1996) trips through densely populated areas have a relatively high share of walking and a relatively low share of car usage and trips through green areas have a relatively high share of cycling and a relatively low share of public transport. Regarding temporalities, public transport shares are higher during peak hour and night-time trips have a relatively high share of cycling and a relatively low share of car usage. Unlike most existing studies, we included in our models also whether trips are made directly or via a detour. It appears that trips via a detour are more likely performed by active transport modes and less likely by car.

Weather appears to have a modest impact on mode choices. This modest impact is not surprising, because we introduced in our analysis many new control variables. This controlling ensures that the presented effects better describe the relationship between weather and mode choices. Some interesting significant effects appear. In congruence to the literature (e.g. Sabir, 2011; Creemers et al., 2014) and the descriptives, lower air temperature ( $T_a$ ) classes significantly reduce cycling shares, while the shares of walking and public transport increase. A negative parameter sign for temperatures above 25 °C compared to reference temperatures of 20–25 °C, although not significant, may even indicate a potential negative effect of heat on cycling, as found by several earlier studies (e.g. Ahmed et al., 2012; Lewin, 2011; Miranda-Moreno and Nosal, 2011). Precipitation sum (Psum) positively affects public transport usage, mostly at the cost of cycling. The effects of wind speed (Ws) and snow cover are not significant. In contrast to the descriptives, sky clearness indicated by the Clearness Index (CI) does not have a clear significant effect on transport mode choices.

### 3.2.2. Perceived temperatures

The effects on subjectively perceived outdoor thermal condi-

tions are presented in the second column of each of the four models in Table 1 indicated by “Tfeel”. Subjectively perceived outdoor thermal conditions will be regressed on the independent personal and weather variables, as well as on the dependent variable mode choice (see Fig. 2). Regarding the effects on perceived outdoor thermal conditions, the four models for the different transport modes are more or less similar and differ mostly with respect to the effect of the mediator transport mode. The explained variances for perceived temperatures are large with  $R^2$  values of 69%.

First of all, perceived outdoor thermal conditions appear to be strongly related to observed weather conditions. In comparison to the reference temperature 20–25 °C, the lower an air temperature class, the more negative its standardized coefficient, while temperatures above 25 °C show a significant positive effect. However, when controlled for this strong effect of observed air temperature, it appears that, with the exception of snow cover, also the other weather variables have strong significant effects. Congruent with several thermal comfort studies (e.g. Eliasson et al., 2007; Thorsson et al., 2011), increased cloudiness – indicated by lower Clearness Index (CI) classes – and higher wind speed lead to colder thermal experiences. In addition, and this has not been studied before, we also found that darkness and larger precipitation sum leads to colder thermal experiences.

In addition to the weather, several personal attributes and attitudes were found to influence thermal experiences. Women, older people and persons who indicated summer as their favourite season, all perceive thermal conditions significantly colder. These findings are congruent with biometeorological insights, indicating higher thermal cold discomfort amongst women (e.g. Karjalainen, 2012; Kenawy and Elkadi, 2012) and lower thermal sensation values for older age groups (e.g. Tuomaala et al., 2013). Obesity was not found to affect perceived temperatures, which is in congruence to earlier studies showing very marginal effects of body mass index (BMI) on thermal sensation (e.g. Tuomaala et al., 2013). The model also shows that people with a non-western ethnicity, often from warmer climate regimes, perceive thermal conditions as colder than native Dutch people, but this effect is not significant.

Finally, it appears that perceived outdoors thermal conditions are affected by mode choice. When cross-comparing the different transport mode models, it becomes clear that active transport mode users, especially weather-exposed cyclists, experience thermal conditions as significantly colder than the more weather-protected users of motorised transport modes. Of all transport mode users, car drivers, sheltered by the protected thermo-regulated environment of their private car, are directly affected by weather conditions only while walking from or towards their parked car. As a result they perceive outdoor temperatures as least cold.

### 3.2.3. En-route place valuation

The effects of en-route place valuations (Place-v) are presented in the third column of each model in Table 1. The  $R^2$  values for en-route place valuations are lower than for the previous dependent variables. This is no surprise as place valuations are highly subjective and could be affected by many unknown external factors outside the model. Nevertheless, the models explain around 10–13% of en-route place valuations and some interesting significant effects can be identified. Before we turn to the effects of weather, we will first briefly summarise the effects of other background factors on people's en-route place valuations.

Descriptively we found that route environments have an effect on people's impressions of their travel surroundings in terms of aesthetics, liveliness and friendliness (Section 3.1). In contrast, address density, building diversity and percentage of green surface have no significant effect on the place valuation construct when tested multivariately. Also personal background characteristics

<sup>6</sup> For instance compared to earlier Dutch studies taking into account the effects of weather, but not in relation to subjective experiences of place and weather (e.g. Sabir, 2011; Böcker and Thorsson, 2014).



have no clear significant effect on en-route place valuations. Only for education a significant effect can be observed. Higher and middle educated people seem to have a less positive impression of their travel surroundings than lower educated, possibly related to more critical assessments of place and aesthetics in general, or to hastier or more routinized travel patterns and/or multitasking, which could all result in less attention for spatial surroundings (e.g. Katz and Aakhus, 2002).

In contrast to the marginal effects of personal backgrounds and static spatial attributes, en-route place valuations are more significantly affected by dynamic attributes of trip environments, as well as by various situational trip attributes. People value their travel surroundings higher when accompanied by others, compared to when travelling alone. A reason could be that spatial experiences are enhanced when people can share them with others. Another reason could be that the very presence of acquainted fellow travellers distracts people's attention away from physical spatial surroundings. Subsequently, people's place-valuations might be affected by social interactions with fellow travellers, which may directly improve valuations of friendliness and liveliness. Place valuation is also higher during trips deliberately made via a detour. It could be that trips via a detour are often made via scenic or pleasant routes, selected specifically by the respondent for aesthetic qualities or qualities related to the social atmosphere.

Temporalities also matter. People value place more negatively during the night-time hours between 12 am and 6 am. Possible explanations could be related to reduced daylight and absence of people on the streets, which may affect aesthetics, friendliness or liveliness. No significant differences can be observed between weekdays and weekends, or between peak and off-peak travel. However, potential variations for these temporal aspects may be captured within the strong effects of trip purpose. People value their spatial surroundings much more during leisure trips than during errands, social and particularly work trips. There may be several reasons for this. From another study we know that people have generally more positive emotions during leisure trips (Böcker et al., 2014), which may subsequently mediate cognitive processes like place valuation (e.g. Blaney, 1986; Kuiken, 1991). Another reason could be that work or errands trips are often more of a routine, often with the same transport mode and via the same routes. During such routine trips through well-known spatial environments, people may pay less attention to their spatial surroundings, compared to possibly more spontaneous or exciting leisure trips. A final reason could be that during leisure trips, people have more time to select more pleasant routes, and/or to more intensely enjoy the qualities of the spatial surroundings.

In addition, also the dynamics of weather play an important role. The multivariate results largely confirm the descriptives in the literature described in Section 2.1. Air temperatures between 20 and 25 °C (reference category in Table 1) result in the most positive place valuations. Colder air temperatures (below 15 °C), as well as hot air temperatures (above 25 °C) have significant negative effects. People's en-route place valuations are negatively affected by precipitation, cloudy sky conditions and, most dominantly, darkness. In contrast to earlier research (Eliasson et al., 2007) as well as our descriptive results, when controlling for all of the above, wind speeds have no significant effect on place valuation. In addition to the direct effects of weather on en-route place valuations we tested also the indirect effects via subjective thermal experiences. Warmer thermal experiences (as a combination individual backgrounds and weather conditions described in Section 3.2.2) have a significant positive effect on place valuations.

Finally en-route place valuations vary significantly between the different transport mode users. Our results demonstrate that active transport mode users have more positive place valuations than users of motorised transport modes. There may be several reasons

for this. First, positive place valuations may be related to the satisfaction with travel in general. An expanding field of studies that connect travel to subjective wellbeing (e.g. Ettema et al., 2011; Abou-Zeid et al., 2012; Olsson et al., 2013) demonstrates that transport mode choices and switches thereof affect satisfaction with travel and affective as well as cognitive wellbeing. In particular the use of active transport modes contributes to higher levels of travel satisfaction than motorised travel (see e.g. De Vos et al., 2013 for a review). Second, compared to car and especially public transport users, active mode users – at least in the Dutch context of pedestrian/bicycle friendly infrastructure – may have more freedom to select pleasant routes or even which side of the road to travel. Also while pedestrian and bicycle routes often lead straight through parks or old inner-city areas, car drivers are usually confined to – less unique and more monotonous/boring – spatial environments around arterial roads or highways. Third, active transport mode users are more directly and intensely connected to their spatial surroundings. Wunderlich (2008:139), for instance, describes walking as “principal mode of perceiving and living (embodying) urban places”, through which “we sense and develop a sense of place”. This intense and detailed experience of the spatial environment may result in a more positive valuation of it. In contrast, car users are more distanced from the outdoors spatial surroundings. Particularly in an urban environment, the attention that car drivers pay to the spatial surroundings will be mostly related to the driving task and other traffic. Additionally, the interior space of the private car – equipped with technologies in safety, communication, entertainment, climate control and noise isolation – forms a private bubble serving as a mobile home or work location (e.g. Laurier, 2002). Finally, while travelling at higher speeds motorised mode users see spatial surroundings in less detail and are less easily able to stop, which distances them from their spatial surroundings (Graham and Marvin, 2001; Peters, 2003).

#### 4. Discussion and conclusion

With the increasing societal interest in climate change, scholars from different, mostly separated, scientific disciplines have investigated the travel-behavioural, thermo-sensational and environmental-psychological effects of weather on people in everyday life. Addressing recent calls for a more integrated interdisciplinary approach (Eliasson et al., 2007; Knez et al., 2009; Böcker et al., 2013), this research aims to conceptually and statistically integrate these fragmented insights. Drawing on unique Greater Rotterdam (The Netherlands) travel diary data enriched with hourly meteorological and spatial route attributes derived by means of GIS-analysis, we analyse how weather affects different transport mode users' en-route place valuations in terms of liveliness, friendliness and aesthetics, while controlling for personal/household, trip and spatiotemporal attributes in Structural Equation Models.

Our findings demonstrate that weather forms an integral part of en-route place valuations. Lower (<15 °C) or too high ( $\geq 25$  °C) air temperatures, precipitation and cloudy or dark sky conditions, have direct significant negative effects on en-route place valuations. This could for instance be related to reduced presence of people outdoors affecting liveliness or friendliness; lower light intensities affecting aesthetics; or less pleasant emotions mediating place valuations in general during these weather conditions. In addition to this direct effect, our findings reveal that warm, clear, dry and calm weather conditions result in warmer thermal experiences, and indirectly in more positive place valuations.

Besides the effects of weather, this paper shows that emotional travel experiences differ substantially between the different transport modes. Being more intensely and intimately connected to their physical surroundings while travelling, active mode users

have overall more positive en-route place valuations than public transport and especially car users. However, during cold, wet and windy weather this closer connection may also have its backside. Active mode users – more exposed to these disadvantageous weather conditions than more protected motorised mode users – perceive thermal travel environments as colder, indirectly lowering their place valuations. Besides weather and mode choice, other trip-specific situational factors appear to play an important role in place valuations. For instance people value their travel surroundings more when travelling during daytime, in company, for leisure, or via deliberate detours.

In contrast, place valuations seem less affected by static spatial route attributes (i.e. greenness, building usage diversity and address density). Although our descriptive findings suggested a relationship – i.e. greener route environments are associated with higher aesthetic and friendliness valuations; densely and diversely built environments with lower aesthetic but higher liveliness valuations – our multivariate analyses show no significant relationships between objective route environments and overall subjective place valuations. This may be a result of our data matching process. Because we have only origin and destination data available, and not the actually taken routes, we had to model people's shortest routes and apply a 200 m buffer in case people take slightly different routes. Also we link en-route place valuations to spatial attributes averaged over the course of an entire route. Due to this broad buffer and/or aggregations we may have lost some detailed spatial variation.

The insights generated in this paper could be valuable for policy makers in several ways. First, our findings on subjective place valuations of travel environments give insights into travel beyond the traditional instrumental factors like time and cost, but as a value in itself affected by the dynamics of travel environments. These insights could help policy makers to better understand how and why travel demand for different transport modes fluctuates with the dynamics of time, place and weather. Second, as travel is an important aspect of our increasingly mobilised world, our findings on different transport mode users' en-route place valuations, translate directly into liveability of urban areas and the subjective well-being of its mobile residents. While weather-protected motorised mode users' place valuations are less affected by weather conditions, urban planners, depending on their local climate's present and projected future challenges, are advised to particularly consider active transport mode users' exposures to cold, heat, precipitation and/or wind. This supports the importance to expand climate-sensitive urban planning from its uses in landscape architecture (e.g. Lenzhöfner and Wulp, 2010; Eliasson et al., 2007) to the transport domain. Examples may include the implementation of deciduous trees (e.g. Konarska et al., 2014), precipitation shelters and/or wind barriers in outdoors urban places or along infrastructures frequented by cyclists or pedestrians, and could enhance liveability and usage of such outdoor environments.

This study provides a new interdisciplinary exploration into the relations between weather, urban form, travel and people's experiences of weather and place. Future research could elaborate these themes into several directions. First, two methodological issues in this research need to be further addressed. In order to deal with the challenge to estimate a multinomial mediator in SEM, this study specified transport mode choice as four binary variables, each in a separate model. However, in reality the choice of transport mode is one between modes and not a dichotomous choice regarding each mode. Future studies may further address this issue, by estimating transport mode choice as a multinomial mediator via the introduction of an equivalent latent class variable (Muthén, 2011), or by specifying four dichotomous mode choice variables allowed to be correlated in one model in order to take the dependencies of the various choices into account. Another

methodological issue to be further addressed is that of the causality between transport mode choices, weather and travel experiences. To do so, studies could make more explicitly use of the longitudinal structure of travel diary data. For instance, in Latent Growth Models the effects of weather on mobility behaviours and experiences at one point in time can be related to its effects at previous and later points in time. Second, the relationship between objective spatial configurations of route environments and subjective place valuations should be further explored. It is important that en-route place valuations are directly linked to accurate Global Positioning System tracked route environments. In conjunction, the sensitivities of multiple buffer sizes on the statistical model may be evaluated. Also route environments should not only be applied to trips as a whole, but also to separate trip segments to address detailed spatial configurations on smaller spatial scales – i.e. the neighbourhood or even street level. Third, to properly address the effects of microclimate conditions the effects of weather on place valuations should be linked, not only to weather data from the nearest (often rural) meteorological station, but also to detailed local microclimate data gathered throughout the urban fabric. Fourth, research may further explore the potentially different vulnerabilities to weather of different social groups. In this study we found some evidence that women and older aged people have colder thermal experiences. However, the effects of these and other attributes like ethnicity need to be further explored, not only on thermal experiences but also on place valuations. Finally, research may analyse the effects of weather on place valuations in direct conjunction with other interrelated subjective experiences, such as travel satisfaction or emotional state. This could provide alternative new insights into the expanding debate on travel, satisfaction and wellbeing (e.g. Ettema et al., 2011; Abou-Zeid et al., 2012; Olsson et al., 2013; De Vos et al., 2013), which is currently largely investigated without considering the role of weather.

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