Introduction

Current city living and upbringing in urban environments have been related to various manifestations of stress and a higher risk of mental health problems. Lederbogen et al. (2013), for instance, have named a set of influencing factors for urban social stress such as infrastructure, socio-economic factors, and noise and environmental pollution. Yang and Matthews (2010) explored the associations of social and built environment determinants with self-rated stress, finding that social stress research can be expanded in scope if measures of the built environment are included. A systematic review from Gong et al. (2016) focused on the relationship between objective measurements of the urban environment and psychological distress. They demand that future work look at the spatial-temporal dynamic of the urban environment measured in GIS in relation to psychological distress.

Lazarus and Folkman (1984) state that stress is a relationship between the person and the environment that is appraised by the person as taxing or exceeding his or her resources and endangering his or her well-being. The concept of stress has been used to specify environmental characteristics that may lead to physical or psychological discomfort and, in some cases, ill health (Evans and Cohen 1987). The authors refer to such factors as environmental stressors. Assessing stress within an objective perspective remains difficult. Many existing instruments for measuring psychological distresses focus on general health outcomes, or depression or anxiety for clinical reasons (Eaton et al. 2004; Goldberg and Williams 1988; Kessler et al. 2002), while others are sensitive to examining task stressors (Helton and Näswall 2015; Müller and Basler 1993). Following Lazarus (1990), subjective measures like self-rated stress are believed to better capture the combination of environmental demands and coping ability and are an appropriate measure to use in the absence of a complete inventory of stressful events.

Human behaviour and perception have been linked to spatial configuration and morphology. Some of the findings have been how street networks influence the way people move, as in the theory of natural movement (Hillier et al. 1993) or how visual fields’ characteristics relate to emotions (Kuliga et al. 2013). Urban typologies (classified by form and function) determine the types of activities that are allowed or discouraged, in turn predicting the existence of certain environmental stressors—such as noise, pollution, crowds and high traffic, among others. In this chapter it is assumed that open public space (OPS) typologies (e.g. park, square, courtyard, pedestrian zone, medium traffic street, heavy traffic street) are important predictors of perceived urban stress.

With the advancement and greater availability of mobile sensors, researchers have investigated pedestrians’ emotions by gaining physiological effects such as heart rate (Song et al. 2013),
skin conductance (König et al. 2014) and brainwaves (Aspinall et al. 2013; Neale et al. 2017). While these studies offer valuable new insights into the role of green spaces and streetscapes, they are still of an explorative nature. All of the above studies use small numbers of test persons, and Aspinall et al. (2013) report on the limitations in terms of data accuracy. Whereas recent research has focused on the role of green space in mental health in response to social determinants (Roe et al. 2017), it remains an open question which built environment factors are critical to influencing perceived (negative) stress in pedestrians, and how they become effective on different scales of planning. In this chapter, the authors report on a series of case studies carried out with a group of architecture students and in open public spaces in Darmstadt, a mid-sized European city.

The chapter addresses the following questions:

1. How do the selected properties such as building density, street network, isovist characteristics and typology relate to pedestrians’ ratings of OPS as being stressful?
2. How do these properties interact with each other?
3. What conclusions can be drawn to improve the accessibility of public space for vulnerable population groups?

**Research Approach**

In the first step, a framework of relevant built environment factors was derived from a literature review (Knöll et al. 2014, 2017). In the second step, environmental data was constructed for 22 open spaces in Darmstadt and is represented in a series of case studies. The figure illustrates the map of Darmstadt’s street network, with street segments weighed according to their global integration (r=n), and ratings of the 22 selected OPS as being maximum stressful (black) or minimal stressful (white).

**Figure 15.1** A map of Darmstadt’s street network. Street segments are weighed according to their global integration (r=n), and ratings of the 22 selected OPS are indicated as being maximum stressful (black) or minimal stressful (white).

Source: Knöll et al. (2015).
public spaces in the city of Darmstadt using GIS and space syntax and paired with subjective ratings of perceived urban stress using multivariate statistical analysis (Figure 15.1). In the third step, single built environment factors have been analysed in a selected type of public space, i.e. a public transport hub, using a smartphone-based app (Figure 15.2). In the following sections, the authors introduce these three research steps.

**Theoretical Background**

Bielik et al. (2015) investigate how space syntax properties can be used to predict the effect of urban form on a wider scope of environmental appraisal. Using principal component analysis they reduce 11 adjectives into three main components labelled *appeal*, *activity* and *spatial experience*. Whereas they find the latter two components, activity and spatial experience, may be well predicted by a single property of urban form, they state that appeal might be more complex and therefore would have to be modelled with multiple urban attributes. They suggest a combination of local attributes such as isovists and of global or relational attributes such as integration to relate to people’s ratings of appeal. Their model uses properties of the built environment only, but was not able to specify aspects of environmental appeal related to urban stress.

Environmental aspects that have been related to various manifestations of urban stress in other studies include noise, crowding of residents, extreme heat waves and air pollution (Evans and Cohen 1987), motorized traffic (von Lindern et al. 2016) and lack of green space (de Vries 2010).
Data Collection and Sampling

OPS are defined as outdoor open spaces that can be owned by public or private entities, but are accessible to the general public. To investigate the relationship between objective measures and subjective cues on perceived urban stress in OPS, variables from an external dataset of environmental properties as well as variables collected from a self-administered online survey about subjective perceptions have been used. The survey consisted of a set of 11 bipolar adjectives which captured environmental characteristics like safety, vegetation, brightness, noise, maintenance, opportunities to sit, traffic, spaciousness, liveliness, relaxation and stressfulness. The independent variable perceived urban stress was collected from the questionnaire and defined as the user’s ratings of an urban environment as being maximum or minimum stressful on a 10-point bipolar scale. In the questionnaire it was suggested that the environmental characteristic of stressful (i.e. perceived urban stress) has a negative connotation, as opposed to ‘relaxing’. The lowest value is ‘1’, meaning ‘not stressful’; the highest value is ‘10’, meaning ‘maximum stressful’ (Knöll et al. 2014).

Data of building density were taken from the masterplan of the city of Darmstadt (Germany) in 2015. Similarly to Wineman et al. (2012), for each reference point assumed in one OPS, a radius of 250 metres (m) was set to define the lot area for which to calculate density values and ratios.

For constructing the space syntax variables, DepthmapX software (Varoudis 2012) was used with a map of Darmstadt on the basis of OpenStreetMap (OpenStreetMap Foundation 2015), to which footpaths were added based on satellite photos provided by Google Maps (Google 2015). The representation of the street network was chosen as a cleaned map of centre line segments, with the radius for integration analysis \( r = 1200 \text{m} \), \( r = 3000 \text{m} \), \( r = n \), which have been shown as good predictors for pedestrian movement and intra- and inter-city motorized traffic. Point-based isovist measures (see Figure 15.3) were constructed for each OPS in its most visible point (Knöll et al. 2015).

Darmstadt has a population of about 150,000 inhabitants and is situated within the Rhine–Main metropolitan area 30 kilometres south of Frankfurt, Germany. Knöll et al. (2014) selected the sample of OPS in Darmstadt within a sector of 500m stretching from the industrial western periphery, across the city centre to the eastern periphery, with predominantly low-rise single-family housing (Figure 15.1). The goal of this explorative research study was to reach respondents with a high expertise in analysing and articulating complex patterns in built environments. Therefore, the authors conducted the empirical research with similarly aged bachelor students from architecture and urban planning programmes at Technische Universität Darmstadt (TU Darmstadt).

A total of 134 respondents completed the survey in December 2013 and in January 2014 (Knöll et al. 2014). Approximately 67% of respondents were female and 33% were male, not according to the representative distribution of the German population. Statistical analyses show that gender has no significant influence on perceived urban stress and therefore has no biasing effects on the results. The same is true for the independent socio-demographic variables age and domicile. Around 57% of the respondents resided in Darmstadt, and the remaining 43% in neighbouring cities like Frankfurt, Mannheim, Mainz or smaller cities. The age range of 22 to 35 years fulfilled the range of the sampling frame. The median value and the average age were 25 years. Upper and lower quartiles were 26 and 24 years respectively, which already indicates a small \( SD = 2.2 \) (Knöll et al. 2017).

Focus on Visibility in a Busy Transport Hub

The Luisenplatz is the main square and central transport hub of the city. It has a symmetrical cross-shaped ground plan with flat, even paving free of platforms and few visual barriers (i.e. a 33m high monument in its centre and see-through bus stops), allowing free flow.

It was renovated in 1980 to meet the demands of rising pedestrian and motorized traffic flow. It was then praised for its value as a ‘framework to balance potentially conflicting functions—a large
public transport terminal versus a recreational square for pedestrians’ (Gehl and Gemzøe 2008). In spite of being free of car traffic, motorized traffic has increased since then, to a total of about 2,100 bus and tram movements a day.

The OPS was selected for a more detailed analysis because of its importance to everyday urban life and manifold surrounding land uses as well as because of its rating among the students: it was chosen as the most stressful place in the city (Knöll et al. 2014). From the study, loudness, heavy traffic and poor vegetation were identified as determinant environmental factors for ‘stressful’ OPS.

For this focus study on Luisenplatz, a combination of visibility graph analysis (VGA) and point isovist analysis was constructed (Figures 15.3 and 15.4). The isovists are based on participants’ ratings of perceived stress assessed on-site by a group of visiting international bachelor and master students (n = 17). Participants were asked to walk freely within the OPS and mark distinctively stressful and relaxing areas, and rate environmental and behavioural properties using the smartphone application MoMe (Halblaub Miranda et al. 2015).

Both VGA and isovist measures were limited to a 250m radius from the centre of the square. Environmental properties such as loudness and exposure to traffic were controlled with structured observations as well as assessed through participants’ statements.

VGA was used to calculate the visual integration of the space itself (Turner 2001). The urban space was reduced to a grid system of a 1m mesh in order to construct the visual relations and the relation of the OPS to its surroundings. This dense mesh allowed sufficient representation of every urban element and narrow street in the vicinity, as presented by Cutini (2003).

The photographed motifs were clustered by themes and spatial proximity in areas of 10m radius, delivering vantage points, which were chosen according to how often the areas—and not phenomena such as crowding or litter—were rated as stressful. From users’ photographs, four main stressful areas could be identified (Figure 15.4). Ratings were analysed for each area separately.

Results

In this section, we report on the findings from literature analysis and the empirical case study with respect to relations found between pedestrians’ ratings of stress and building density, street network, isovist characteristics and open space typology. The section is concluded with some remarks on how these factors interact with each other.

Building Density Needs to Be Differentiated

Urban density has been seen as influential on city dwellers’ mental life and well-being since the beginning of modern great cities (Simmel 2006). In more recent years and in stark contrast to this preconception, the compact city as a form of distinguishable settlement characterized by a high density of buildings, infrastructure and services has been related to various positive effects on quality of life and health (Adli 2017). Most studies, however, have focused on overall physical activity

Figure 15.3 Generating the isovist characteristics from the sample of 22 OPS.
Source: Knöll et al. (2015).
or better access to public space for vulnerable groups (Burton and Mitchell 2006). For the sample of open spaces in Darmstadt, Knöll et al. (2017) found that building coverage ratio, defined as the buildings’ footprint per area, was positively related to pedestrians’ perceived urban stress. Indeed, building coverage ratio had the highest single share (17%) of built environment factors explaining a high variance of perceived urban stress (Table 15.1). Interestingly, floor area ratio,
Public Space and Pedestrian Stress Perception

defined as total area of floor space, i.e. including building heights, decreases the coefficient of determination $R^2_{\text{Prop}}$ about 1.2% compared to building coverage ratio. This means that building heights in a radius of 250m around a vantage point play a relatively small role in explaining perceived urban stress in OPS (Knöll et al. 2017). This may be explained by the relatively low building heights (maximum five floors) in Darmstadt, but may also be due to the fact that building coverage ratio is closely connected to the amount of green space available in an area.

**Walkable vs. Car-Friendly Street Networks**

The degree of integration of particular street segments in the urban grid has been considered a pervasive indicator for pedestrian movement patterns (Hillier et al. 1993). Sarkar et al. (2013) have used street network characteristics of neighbourhoods in a rural county of Wales, and related them to data of self-reported psychological distress in older men. They found that high global integration ($r = n$) values are related to higher odds of psychological distress in older men. In contrast, high levels of local-level accessibility, for example high values in local integration ($r = 1200m$), are associated with lower odds of psychological distress. According to their explanation, the high value of local integration is associated with high walkability of the area, where respondents would have more access to public life and care facilities.

For the case study in Darmstadt, Knöll et al. (2015) found that high global integration values ($r = n$) and high citywide integration values ($n = 3000m$) are positively related to ratings of OPS as being stressful (see Figure 15.1). This can be explained by the correlation of motorized car traffic in the respective street segments. Using multivariate regression, Knöll et al. (2017) found that street

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**Table 15.1** The environmental factors found to be related to ratings of perceived stress in open public spaces

<table>
<thead>
<tr>
<th>Dependent variable: urban stress levela</th>
<th>Standardized beta coefficient (SBC)</th>
<th>Percentage of the absolute sum of all SBC</th>
<th>Sum</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Building density</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Building coverage ratio</td>
<td>0.514**</td>
<td>17.17%</td>
<td></td>
</tr>
<tr>
<td><strong>Street network</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Ln citywide integration</td>
<td>0.210**</td>
<td>7.02%</td>
<td></td>
</tr>
<tr>
<td>• Ln local integration</td>
<td>−0.394**</td>
<td>13.16%</td>
<td></td>
</tr>
<tr>
<td><strong>Isovist</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Visibility</td>
<td>0.321**</td>
<td>10.73%</td>
<td></td>
</tr>
<tr>
<td>• Ln perimeter</td>
<td>0.417**</td>
<td>13.93%</td>
<td></td>
</tr>
<tr>
<td>• Square vertices number</td>
<td>−0.369**</td>
<td>12.33%</td>
<td></td>
</tr>
<tr>
<td><strong>Open space typology</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Park (park = 1)</td>
<td>−0.140*</td>
<td>4.68%</td>
<td></td>
</tr>
<tr>
<td>• Heavy traffic streets</td>
<td>0.100</td>
<td>3.34%</td>
<td></td>
</tr>
<tr>
<td>• Courtyard</td>
<td>−0.223**</td>
<td>7.45%</td>
<td></td>
</tr>
<tr>
<td>• Medium traffic street</td>
<td>−0.124*</td>
<td>4.14%</td>
<td></td>
</tr>
<tr>
<td>• Pedestrian street</td>
<td>−0.181**</td>
<td>6.05%</td>
<td></td>
</tr>
</tbody>
</table>

Source: Knöll et al. (2017).

Notes: a Random-effects GLS regression [corr(u_i, X) = 0 (assumed)]; ** and * indicate significance at the 1% and 5% level.
network characteristics are good indicators for perceived urban stress, holding a 20% share of all built environment factors (Table 15.1). In addition, local integration values \((r = 1200\text{m})\) relate negatively to perceived urban stress. OPS in walkable areas, as indicated by their high local integration values, are less likely to be perceived as stressful. These findings are in line with previous work, in which exposure to car traffic was related to negative affective responses (Bornioli et al. 2018; Tilley et al. 2017). They extend an earlier study, in which high local integration was related to lower odds of self-reported psychological distress in older men (Sarkar et al. 2013), to a younger age group, i.e. university students. Overall, our results confirm that open spaces in less walkable areas are more likely to be perceived as stressful. The data also suggest that stress perception can be predicted and potentially influenced by street network characteristics.

**Visibility Is Key to Pedestrian Safety**

In order to assess physical and psychological experiences of outdoor spaces, Osmond (2011) points to the traditional measures such as isovist area, perimeter, maximal radials, occlusivity (Benedikt 1979) and compactness (Batty 2001). Isovist area is commonly defined as the amount of space which is unobstructed by built space of any kind at eye level (160 cm) seen from a vantage point in an OPS and measured in square metres (Figure 15.3). Visibility is defined as the relative size of all isovist areas in a system, retrieved from an analysis of multiple positions by computing the visibility of positions regularly distributed over the whole environment (Turner et al. 2001).

In our sample, the data show that high visibility levels in OPS (e.g. a spacious space) are positively related to perceived urban stress, explaining an 11% share of the built environment factors (Table 15.1). This is contrary to findings previously reported in public buildings in which visibility was positively related to perceived safety (Kuliga et al. 2013). And it is somewhat surprising, since visibility of pedestrians by car drivers is key to reducing traffic injuries and improving overall actual pedestrian safety (Stoker et al. 2015). In other words, people seem to perceive urban stress in highly visible areas of busy squares and streets, where, in theory, they should be safest from car traffic.

In the case study of the transport hub in Darmstadt, visibility was investigated in more depth, producing a heat map of different levels within one open space (Figure 15.4). The data show that visibility of four tested points within the same OPS has a weak negative relation to perceived urban stress, i.e. the opposite direction of effect to that reported above.

Area 3 in Figure 15.4, rated as most stressful \((M = 7.60)\), has the lowest visibility (taken from the VGA) and lowest vertices number (341). It is followed by area 4 with a rating of \(M = 7.17\) and 388 isovist vertices. Both areas are on the east side of the OPS, where the majority of buses stop (Figure 15.4).

On the west side, area 1 follows in the ranking with a rating of \(M = 6.43\) on perceived stress and a total of 406 vertices, and finally area 2 has a perceived stress of \(M = 4.75\) and the highest number of vertices (451). These results endorse the ambiguity of visibility in relation to perceived stress, depending on the scale of analysis (citywide versus open space), the absolute size of an area and other finely grained factors such as the location of transport stops and street furniture.

In addition to visibility, Osmond (2011) underlines that perimeter as the total outline is an important factor when studying visual stimulation in terms of the information available in a given surrounding environment. Examples for OPS with high perimeter in relation to area are heavy traffic streets and squares. The data gained in our survey confirm that perimeter is positively related to perceived urban stress, with a high share of 14% in all built environment factors (Table 15.1).

A third group is related to the complexity of its outline. From empirical studies with virtual reality environments, Franz and Wiener (2008) also relate openness ratio, vertices number and vertices density as an indicator for arousal. Wiener et al. (2007) show that vertices number specifically relates to user ratings of complexity and interestingness. Vertices number is defined as the total amount
of vertices of an isovist perimeter and vertices density as the standardized index of vertices number divided by isovist total area. A weak relation was found between the vertices density and participants’ ratings of safety (Knöll et al. 2015). Examples of OPS with high vertices numbers are high streets, with high perimeters and complex edges, i.e. building facades that jump back and forth, small block sizes and so on.

While Franz and Wiener (2008) have shown vertices numbers related positively to the perception of complex and visually interesting indoor spaces, our data suggest that high vertices numbers are negatively related to perceived urban stress in our samples. Vertices number and perimeter have an effect, with alternating directions but similar strength, on perceived urban stress. This means that large streetscapes with low vertices numbers, i.e. with low detailing and low complexity in their building facades, are more likely to be perceived as stressful. This provides data for architects and planners, who criticize large spaces with less spatially detailed building walls, for example a blank concrete wall on the pedestrian level instead of a more transparent facade, as not in line with human scale (Gehl 2012).

We conclude that further studying the isovist characteristics and their relation to perceived urban stress should be a priority in future research. Visibility and the geometric shape (‘complexity’) of urban environments are factors that can be influenced by urban design measures such as street furniture, public transport stops, trees and facades. We suggest that enclosure can be a further influencing factor to be taken into account when comparing different typologies of OPS.

**Open Space Typology Is the Best Predictor of Stress**

Much research on health-promoting mechanisms, including increased physical activity, social interaction, restoration and stress relief, has focused on green spaces (Nieuwenhuijsen et al. 2014). Less attention has been given to ‘grey’ urban environments including streetscapes and squares. Recently, Bornioli et al. (2018) showed in an experimental study that pedestrianized, ‘high-quality’ urban settings have positive effects on self-assessed relaxation, perceived qualities and perceived restorative affects as opposed to commercial areas with exposure to motorized traffic. The authors distinguish between usages (mixed versus commercial) and architectural style (historical versus modern), with green space as a third category. We introduce the six open space typologies of square, park, courtyard, heavy traffic street, medium traffic street and pedestrian zone to choose our sample of OPS based on place names and available traffic data.

As anticipated, respondents rated environmental characteristics such as spaciousness, vegetation, brightness, maintenance, traffic, noise, seating, liveliness and safety as very different for the typologies of OPS used in this set-up. The average ratings of an OPS being perceived as ‘maximum stressful’ were $M = 7.52$ for all heavy traffic streets, and $M = 7.56$ for all squares, while all parks were rated as only $M = 2.53$ on average.

The impact of all six open space typologies accounts for 26% of the explanation of perceived urban stress (Table 15.1). In our sample, heavy traffic streets and squares are not statistically different from each other. In comparison, perceived urban stress is rated 1.0 lower in medium traffic streets and parks. It is rated 1.2 lower in pedestrian zones and 2.1 lower in courtyards.

**The Relative Importance of Different Factors**

Building coverage ratio covers the biggest single share for a property in explaining the variance of perceived urban stress (17%). It is followed by the natural logarithmic term of isovist perimeter (14%), the syntactical property of local integration (13%) and the non-logarithmic terms square vertices number (12%) and visibility (11%) (Table 15.1).
The strong positive correlation between building coverage ratio and perceived urban stress in our sample points to the important role of urban development in promoting mental health. However, it is important to note that building coverage ratio is only one ingredient in a model to better understand perceived urban stress. Isovist (37%) and syntactical street network (20%) characteristics together account for 57% of the variance of perceived urban stress. Citywide integration and local integration act with different directions (different algebraic sign) and strengths on perceived urban stress. As mentioned above, high values in local integration associated with good walkability relate to low values in perceived urban stress, whereas high values in citywide integration associated with motorized traffic are positively related to perceived urban stress. This confirms the importance of measures to reduce and calm motorized traffic in OPS, giving priority to pedestrians over cars (Stoker et al. 2015). The effect of local integration on perceived urban stress is twice as robust as the effect of citywide integration. This may highlight the potential for reducing perceived urban stress by improving walkability, including the introduction of smaller block sizes, better connected street networks and pedestrian infrastructure.

Conclusively, we have found that visibility and building coverage ratio together explain 28% of perceived urban stress. This means that high visibility in an area that has also high values in building coverage ratio is positively related to perceived urban stress. In contrast, OPS with high visibility and low building coverage ratio tend to be perceived as less stressful. The effect of building coverage ratio is 1.5 times stronger than the effect of visibility. These results underline the call for a wider spectrum of parks and gardens, which includes ‘small public spaces’ such as courtyards, free lots and squares (Whyte 1980), providing a greater mix of vistas to OPS.

**A Tool to Predict Perceived Urban Stress from Built Environment Factors**

In a final step, all independent variables—urban density, the isovist and street network characteristics and typology—were included to analyse their influence on perceived urban stress in a multivariate way. The resulting model is able to predict pedestrian stress ratings with a coefficient of determination of $R^2_c = 58.5\%$ using citywide integration, local integration, perimeter, square of vertices number, visibility, building coverage ratio and typologies (Table 15.1). The variance of this equation ($R^2 = 0.585$) to predict perceived urban stress is not as high as the variance of the equation presented by Watts et al. (2014) to predict users’ assessment of tranquillity in green spaces ($R^2 = 0.89$, $p<0.001$). But it is important to note that the model presented here does not require an elaborated and expensive acquisition or analysis of environmental data such as noise levels, or the subjective assessment of users of maintenance conditions. Our model achieves a reasonable predictive power for perceived urban stress with data gained merely from an analysis of the built environment. All properties can be derived from tools such as GIS or space syntax.

**Discussion**

This chapter presents a method to predict ratings of perceived urban stress in outdoor spaces. It is a first attempt to predict more complex emotions such as perceived stress with a set of environmental properties that can be derived from commonly used spatial analysis tools such as GIS and space syntax. It further develops the current approaches, which have focused on appeal and have not aimed to explain more complex emotions such as stress (Bielik et al. 2015). The framework may be particularly useful for describing the built environment more comprehensively in future research, building on emerging interdisciplinary attempts to study affective response using psychophysiological data, which have merely distinguished between green and grey urban areas (Neale et al. 2017) or modern versus historical, mixed versus commercial land use and exposure to traffic (Bornioli et al. 2018).
The results further specify recent findings, which have related living in urban environments to higher levels of urban social stress. The chapter introduces four categories of environmental properties to describe perceived urban stress: a) open space typology, b) syntactical, c) isovist characteristics and d) urban density. The case study finds that open space typologies (park, square, courtyard, streets) are the best predictors of perceived urban stress. They are followed by single properties such as building coverage ratio, isovist vertices numbers, local integration and citywide integration. Our data show that the literature relating isovist characteristics and human perception in indoor spaces can only be extended to outdoors spaces to a limited degree. In fact, perimeter was the only variable which was confirmed as a good predictor with a similar direction of effects when used in indoor and outdoor spaces. Visibility is positively related to stress in OPS, meaning that large spaces, in which one can see a large total isovist area, are perceived as being stressful. While good visibility, i.e. an unobstructed view for pedestrians and car traffic, is key to actual pedestrian safety, it may be compensated for by factors that have been shown to reduce stress ratings. In our case, this was for example isovist vertices number, i.e. more complex shapes of OPS with detailed and diverse edges, such as facades. Overall, our study specifies a first set of environmental characteristics related to perceived urban stress in outdoor spaces. However, our findings call for more empirical studies on isovist characteristics, particularly for outdoor spaces.

The presented data give first hints of possible interaction between factors. Our results suggest that high building coverage ratio is positively related to perceived urban stress in an open space. This is in line with the known importance of providing access to quality green spaces and a wide spectrum of small and medium-sized OPS. At the same time, we found that less walkable open spaces are also likely to be perceived as being stressful. High citywide and global integration (indicating higher volumes of car traffic) relate positively to perceived urban stress, while high local integration (indicating high volumes of pedestrian movement) relates negatively to perceived urban stress. High isovist vertices numbers (indicating complex building walls of OPS) are related negatively to perceived urban stress, too. Our results suggest that positive effects from isovist characteristics and local street integration coexist with negative effects from high building coverage ratio and citywide integration. It remains an open question how the variables presented in this chapter interact with each other. A better understanding would be crucial to assessing if and to what extent characteristics of the built environment related to negative effects in stress perception can be balanced with other characteristics.

Conclusions and Outlook

The chapter explores the role of perceived urban stress in creating quality open spaces that invite physical activity and promote mental health. The results highlight that, next to mostly static variables such as OPS typology and building density, more adaptive variables such as local integration of street segments as well as isovist characteristics play a key role in perceived urban stress. These latter, adaptive variables can be influenced and should be addressed for instance by traffic calming or by urban design measures. Future research should address the interaction of variables in more depth. More empirical data would allow planners and decision makers to prioritize and orchestrate design interventions with respect to mental health and stress. The framework presented here may be used to describe the built environment in more detail in further interdisciplinary research.

The sampling of test persons (i.e. architecture students) was helpful in getting a good response in terms of assessing environmental qualities in this explorative stage of research. Test persons indicated their home address, as well as duration of residency and enrolment at the local university, from which we concluded a grade of familiarity with the city. However, they are not representative of a wider population, as they do represent a certain age group, educational background and occupation. The case study of the transport hub, in which the sample consisted of visiting students from Jakarta, Indonesia, also suggests different patterns in perceived urban stress connected to cultural
background and kind of urban environment of upbringing. Upbringing in cities with a population of more than 100,000 has been shown to be related to social stress and higher risk of mental health problems (Lederbogen et al. 2013). Future research should expand this study to a wider spectrum of the population.

Stress perception was only assessed with an online questionnaire, in which test persons had to assess OPS from memory. This approach was chosen to maximize the sample of OPS rated by participants. Future research should also include assessing OPS on-site, for example using location-based applications and bio-signals.

The sampling of the OPS in Darmstadt includes a wide spectrum of typologies, geometric shapes, locations and context. The resulting model is robust in so far as it can be generalized to other OPS in Darmstadt or other similar cities. However, it remains open how the results can be generalized to other types of cities. Darmstadt is only representative of a middle-sized city in a central European context. Future studies must confirm and extend findings for other demographics, including more vulnerable population groups, and in settlements with lower and higher population densities, first in a central European context with similar cultural and climatic backgrounds and eventually in a global urban perspective.

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