City identity and pro-environmental behavior: A Mixed-Methods Study Using Heat Mapping

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***Abstract*—The article investigates the relationship between city identity and pro-environmental behavior (PEB) among residents of five big cities in Russia: Moscow, St. Petersburg, Krasnoyarsk, Krasnodar and Kazan. The study consists of a two-stage mixed-methods design: (1) an online survey (N = 821) assessing city identity, environmental attitudes, and pro-environmental behavior and (2) a field study involving heat mapping of public spaces to evaluate objective environmental quality and its perceived alignment with residents. Results indicate a statistically significant positive correlation between strong city identity and higher levels of pro-environmental behavior. Heat maps reveal spatial mismatches between perceived and actual environmental comfort, highlighting the need for participatory urban planning that integrates residents' identities and ecological expectations. The findings contribute to urban data practices and sustainable city development.**

***Keywords* - City Identity, Pro-Environmental Behaviour, Thermal Mapping, Urban Sustainability, Mixed-Methods Research**

I. Introduction

Human actions are recognized as a primary driver of environmental negative changes [5], [17], [21]. In this context, pro-environmental behaviour (PEB) defined as actions taken by individuals to minimize the negative impact on activities on the natural environment [18] has emerged as a critical factor in achieving resilient and livable urban areas in big cities, especially megacities. Extensive research has been done to understand the psychological, social, and contextual factors encouraging individuals to participate in pro-environmental behaviour [2], [3], [8]. With the growing urgency and impacts on environmental crisis (IPCC, 2023), in urban environments research remains necessary to inform effective policies and interventions aimed to foster pro-environmental actions. The urban populations have a significant role to play in achieving sustainable goals. PEB encompasses both private-sphere (e.g., recycling, energy and sustainable consumption) and public-sphere actions (e.g., environmental activism, participation in community eco initiatives) [18]. Accessible recycling systems integrated into the urban environment are needed, just as low-carbon mobility options are essential.However, the adoption of such sustainable behaviours remains contingent upon psychological, social, and contextual determinants [9].

In the context of urban planning, 'urban greenery' encompasses designated open spaces such as parks, as well as a variety of natural elements—including vegetation, wetlands, and other ecological systems [13]. Urban green spaces are defined as areas within cities that feature trees, grass, or other forms of plant life [19]. Expanding these green areas plays a vital role in improving urban living conditions, particularly for residents who live in a fast-paced environments and in strong climate conditions. Examples may include botanical gardens, community places, and designed parks for all residents (families, inclusive citizens, and etc.) While traditional parks provide venues for recreation, community gardens foster environmental stewardship and strengthen neighborhood social cohesion. Linear parks, which follow natural contours and pathways, and urban mini forests characterized by dense tree canopies that mimic natural ecosystems further enrich the urban landscape. Tree-lined boulevards, meanwhile, serve as vibrant social spaces that enhance both the aesthetic appeal and functional quality of cities. When strategically integrated into dense urban cores, these diverse green environments enable residents to unwind, connect with nature, and build stronger communal bonds, collectively enhancing a city's overall livability.

Urban green spaces (UGS) are sometimes referred to 'blue-green infrastructure,' as it often incorporates water-based features such as streams, rivers, creeks, drainage channels, and their adjacent banks alongside vegetated areas [23]. Beyond their aesthetic and social value, Urban green spaces (UGS) deliver critical environmental benefits. They help mitigate urban flooding, lower ambient temperatures during hot seasons, and support diverse plant and animal life. Moreover, it contributes significantly to public health, psychological well-being, and social cohesion.

However, access to high-quality green spaces is not equally distributed in Russian cities. Research indicates that neighborhoods with lower socioeconomic status or higher immigrant populations tend to have fewer and lower-quality green spaces compared to more affluent districts [22]. This disparity exacerbates health inequities, as limited access to greenery is associated with poorer physical and mental health outcomes. Compounding the issue, disadvantaged communities often bear a disproportionate burden of environmental risks such as air pollution, degraded environmental quality, and heightened safety hazards. Paradoxically, the very benefits that urban green spaces (UGS) provide enhanced well-being, economic vitality, and improved mental health can drive up property values and land prices, potentially accelerating gentrification and displacement in urban neighborhoods.

Among pro-environmental determinants, city identity has emerged as a theoretically and empirically salient construct. City identity refers to the extent to which individuals incorporate their city into their self-concept through affective attachment, cognitive identification, and symbolic

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meaning [6], [20]. It transcends residential tenure, reflecting a deeper sense of belonging and a perceived continuity between personal and urban narratives [14], [18]. Drawing on place identity theory [15], scholars argue that when urban environments become integral to self-definition, individuals are more likely to perceive environmental degradation as a threat to the self-motivating protective or restorative actions [1].

Empirical studies across diverse cultural contexts have documented a positive association between place identity and pro-environmental behaviors [4], [16]. However, research in post-Soviet urban environments characterized by rapid institutional transformation, cultural heterogeneity, and top-down urban governance remains understudied. This gap is particularly consequential in the Russian Federation, where urban policy underdeveloped and lack of clear directions.

The current study promotes co-creation of public spaces through digital platforms, online surveys, and data-driven diagnostics, positioning residents as active participants in urban transformation. Yet, the behavioral sustainability of such interventions, for instance, whether residents maintain or expand upon newly introduced green practices, depends critically on underlying psychological commitments to place. It can be demonstrated that in the absence of a sense of collective ownership and local identity, infrastructural enhancements are likely to be underutilized [7].

Moreover, the efficacy of urban sustainability policies is contingent upon the congruence between subjective perceptions of environmental quality and objective physical conditions. Discrepancies between the perceived and actual environmental stressors, such as the absence of greenery, have the capacity to erode trust in planning processes and diminish motivation for sustainable engagement [11].

The present study aims to address this gap by examining the interplay between city identity and pro-environmental behaviour across five Russian cities participating in the research. The following cities are included in the study: Moscow, St Petersburg, Krasnoyarsk, Kazan and Krasnodar. The selection of these cities is driven by the necessity to address the existing gap in academic literature. The selection of these cities was driven by the necessity to ensure geographical, climatic, and demographic representatives. The federal districts under discussion are as follows: Central, Northwestern, Siberian, and Southern. The regions are distinguished by a diversity of climate zones, ranging from the temperate conditions of Krasnodar to the extreme cold weather of Krasnoyarsk. A further distinction is the significant variation in population size, from approximately 1 million in Krasnodar to over 12 million in Moscow.

The present research contributes to three interrelated domains. The first is environmental psychology, which involves the testing of the city identity PEB link in a non-Western urban context. The second is urban informatics, by demonstrating the utility of open thermal data for participatory planning, and the third is a public policy by offering evidence-based recommendations for identity-sensitive implementation used in the project. This integrative approach demonstrates that sustainable urban futures are contingent not only on the built environment, but more crucially on the way in which residents engage with the cities.

II. Data Processing

Participants

A total of 821 respondents participated in the study, with 61% of respondents identifying as female and 39% as male. The participants are residents of five major Russian cities, situated in diverse climate zones, and the age range of the subjects spans from 18 to over 65 years. The majority of participants (58%) were aged between 18 and 24 years old. The data was collected via two methods: an online questionnaire and a field study. The population distribution among participants was almost equal across all cities (Moscow –184; Krasnoyarsk – 190; St. Petersburg – 157, Kazan – 141; Krasnodar – 149). Most of the participants have resided in a city for a period exceeding five years.

The initial phase of the study comprised the administration of an online questionnaire. The survey was disseminated online and comprised three validated scales: Pro-Environmental Behaviour (PEB): a 23-item scale, which was grouped into five sub-scales: waste management, social activism, resource conservation, eco-conscious consumption, and climate-related actions [13]; City Identity (CI): a 6-item scale to assess emotional attachment and sense of belonging to one's city; and an Environmental Concern (EC): a 9-item scale, which was divided into three sub-scales reflecting biospheric (concern for nature), altruistic (concern for other people), and egoistic (concern for oneself) orientations.

III. Results

The mean level of pro-environmental behaviour (PEB) was 3.39 (SD = 0.51), while that of urban identity (CI_Total) was 3.58 (SD = 0.85) across all cities. In the context of the behavioural dimensions, resource conservation (M = 3.83) and waste management (M = 3.57) were found to be the most significant, while social (M = 3.23) and climate-related actions (M = 3.04) were comparatively less pronounced.

The implementation of a correlational analysis yielded a significant positive association between CI and PEB ($\rho = 0.34$, $p < 0.001$). The strongest correlations were observed between city identity and resource conservation ($\rho = 0.38$) and waste management ($\rho = 0.31$). The association with social actions was weaker but still statistically significant ($\rho = 0.15$, $p < 0.05$), while the link with climate-related behaviour was non-significant.

All three forms of environmental concern (EC): biospheric ($\rho = 0.34$), altruistic ($\rho = 0.23$), and egoistic ($\rho = 0.26$) were positively correlated with pro-environmental behavior ($p < 0.001$), suggesting that individuals who recognize the consequences of environmental problems for nature and other people are more likely to engage in pro-environmental actions.

Age-stratified analysis indicated that participants aged 25–44 exhibited the highest levels of both PEB and CI in every city. In contrast, young adults (18–24 years) demonstrated moderate behavioral engagement but lower city identity. Respondents aged 45 and older maintained

relatively high city identity scores but reported fewer pro-environmental practices.

Regional differences were also evident. Residents of Moscow, St Petersburg and Kazan cities reported higher city identity but, on average, engaged less frequently in pro-environmental behaviors. It can be explained that there are some pro-environmental practices are not considered as pro-environmental. On another side, participants from Krasnoyarsk and Krasnodar were more likely to participate in concrete environmental actions, such as community clean-ups and waste sorting. It helps to strengthen social cohesion. Also, some actions such as “subbotnik” are only known in our country.

Duration of residence in the city emerged as a significant predictor. Individuals residing in their city for more than 10 years reported the highest levels of both CI (M = 3.83) and PEB (M = 3.49). In contrast, newly residents (<5 years) exhibited the lowest scores (CI = 3.21, PEB = 3.23). These findings underscore the role of place attachment and emotional connectedness in fostering city identity and, consequently, pro-environmental behavior.

For the second part of the study, which was a field study, a custom phygital eye-tracking platform was developed. The stimulus set included static images and 3-D visualizations of urban environments with controlled parameters of green coverage, the amount, type, and spatial distribution of vegetation. Eye movements were recorded via a webcam at 60 Hz. Raw gaze data were pre-processed through blink filtering, temporal normalization, and fixation parsing using the I-DT (Identification by dispersion threshold) algorithm. A convolutional neural network (CNN) identified vegetation typologies, while SHAP (Shapley Additive Explanations) analysis was employed to interpret the influence of each visual parameter. The outputs included heat maps and visual salience scores, later integrated into Building Information Modeling (BIM) and Geographic Information System (GIS) environments for spatial comparison.

Fig. 1 shows an example of the visual format that has been used in the study. The base image (up left) presents the street as a conventional photographic view, appearing as an ordinary streets-cape, with numbered markers indicating measured locations (second picture). Superimposed mapping layers progressively reveal deeper spatial insights. The panel displays an object density map derived from the image, quantifying the distribution and concentration of visible elements. The third panel presents a representation of the geographical distribution of green space, with particular emphasis on the presence and extent of vegetation within the scene. Finally, the last picture presents an attention heat map, generated through eye-tracking platform, which illustrates areas of highest visual focus and cognitive engagement. Collectively, these layers transform a seemingly ordinary street into a rich, data-driven portrait of its perceptual and ecological urban qualities.

Each experimental session yielded three synchronized data layers, forming a comprehensive multi-modal dataset for integrated analysis. The physiological layer comprised gaze coordinates that were sampled at a rate of 60 Hz and logged in CSV format to capture fine-grained oculomotor behaviour. The visual layer comprised annotated stimulus images, encoded in JSON format, which delineated scene elements, regions of interest, and semantic features corresponding to the displayed environments. In addition to these objective measures, the sociological layer incorporated structured questionnaire responses encompassing demographic information, perceptual assessments, and nature-related attitudes, which were collected via the Qualtrics platform. The integration of these co-registered layers within the experimental framework enabled a comprehensive examination of visual attention, environmental perception, and individual differences.

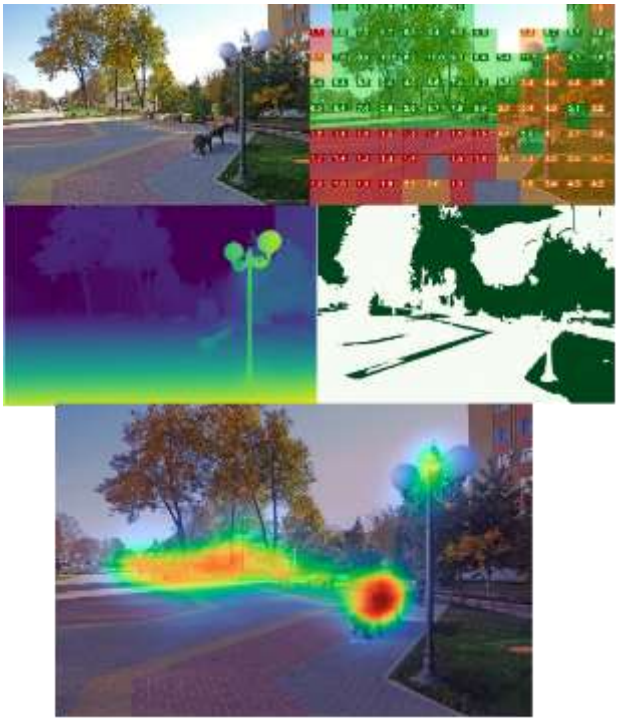

Fig. 1. A multi-layered visual analysis of an urban street environment

All datasets were stored in an encrypted cloud repository under GDPR-compliant participant IDs. Pre-processing included blink filtering, temporal normalization, and segmentation of areas of interest (AOI). Statistical analysis was performed using IBM SPSS Statistics, following the fixation computation procedure.

The hypothesis that vertical greening elements, such as green façades, elicit significantly longer visual fixations compared to ground-level shrubs was tested empirically in the Shanghai eye-tracking study [24], and the hypothesis was corroborated. Furthermore, the hypothesis is put forward that compact integrated green elements alongside a road or a pedestrian area will foster more sustained visual attention than narrow linear green strips (Fig. 2). This hypothesis is supported by the results of virtual reality–based restorative environment assessments (VR-RSA trials). It is noteworthy that edge-avoidance behavior manifests when the width of linear green strips is less than one meter, indicating that corridors of insufficient width are inadequate for maintaining visual engagement.

Preliminary analyses confirm a positive correlation between participants' Nature Connectedness Index (NCI) scores and overall dwell time in green spaces was found to align with the results of prior research conducted in courtyard environments, as examined by researchers [12]. In

order to further characterize visual engagement patterns, participants' gaze behaviors were clustered using k-means analysis into three distinct topological groups: explorers, who exhibited wide-range scanning across the entire scene; focused viewers, whose attention was concentrated on salient or key environmental features; and by-passers, who demonstrated minimal visual engagement with the green space.

Fig. 2. The view of a pedestrian area with integrated green elements

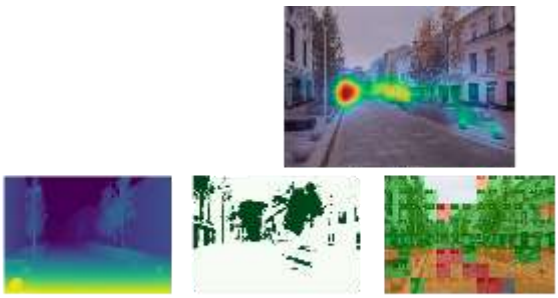

Fig. 3. A heat mapping analysis of the area

The SHAP interpretation module identified the key predictors of visual salience, which are expected to include foliage density, colour contrast, and biodiversity richness [Fig. 3].

IV. Conclusion

The findings tend to support the hypothesis that city identity is a significant predictor of pro-environmental behaviour among urban residents. It has been demonstrated that individuals who experience a profound sense of affiliation with their city are more inclined to demonstrate pro-environmental behaviours.

As indicated by age-related patterns, younger adults engage in individual-level environmental practices yet demonstrate limited involvement in collective or civic forms of environmental action. In contrast, middle-aged adults demonstrate more consistent pro-environmental habits but exhibit reduced activity in socially oriented initiatives. The findings underscore the necessity for targeted engagement strategies, particularly among youth, through platforms that emphasise personal impact and community benefits.

The comparatively low scores on social activism may be indicative of the prevailing sociocultural norms in Russia, where private and household-level environmental behaviours are more prevalent than public or politically engaged forms of action. This underscores the importance of fostering trust and participatory culture, potentially through digital citizen science platforms that make individual contributions visible and socially meaningful.

The significant role of environmental concern, especially biospheric, aligns with global evidence and supports theoretical models positing that emotional and cognitive awareness of environmental consequences drives behavioural change.

The integration of eye-tracking and segmentation data into city digital twins enables planners to simulate how different greening configurations affect human perception and spatial use patterns. The findings of this study will serve as a foundation for informed, evidence-based urban design decisions.

The results may also have important policy implications. For example, they could inform the development of guidelines for designing local community initiatives aimed at encouraging pro-environmental behaviours and developing more sustainable public areas. They may also support the development of broader strategies to enhance the quality of urban life and foster more sustainable lifestyles in a rapid growth of big cities' population. Furthermore, they could promote greater self-awareness and reflective evaluation of everyday environments [14].

It is imperative that research into urban green environments (UGEs) and their multifaceted contributions to the social, economic and environmental well-being of residents is continued in order to foster resilient and sustainable urban environments. This research has explored several dimensions from their profound links to public well-being and urban growth. A number of critical insights and recommendations are posited.

The integration of green infrastructure into urban development has become imperative, particularly in metropolises characterised by inclement weather conditions. When urban planning is executed from a holistic standpoint, encompassing biodiversity conservation, water conservation, and inclusive access, green spaces evolve into a functional component of the urban landscape. Achieving a health-promoting environment for both people and ecosystems necessitate close collaboration among urban planners, architects, environmental experts, and local communities.

The success of UGS is contingent on the sustained engagement of the community throughout all phases of the project, from the initial design and planning stages to the ongoing maintenance phase. This involvement should not be a one-off consultation, but rather an ongoing process that cultivates a shared sense of responsibility and belonging. The employment of effective methodologies, such as the utilization of an eye-tracking platform that has been meticulously designed for the specific purposes of this study, is of paramount importance.

The research suggests that there is a necessity for collaboration between policymakers, urban designers, and residents to achieve sustainable practices involving community voices, and to integrate green spaces at the heart of urban policy. It is imperative to acknowledge the significance of UGS, not solely in terms of its aesthetic appeal, but as a pivotal component of urban infrastructure, which plays a crucial role in enhancing social cohesion and

driving economic growth within the city.

Urban areas have the capacity to be transformed by the introduction of green elements, which can effectively transition isolated spaces into dynamic, integrated systems that enhance urban life. This development is indicative of a shift towards more inclusive, intelligently designed urban environments in which nature and human activity thrive in harmony. The ultimate goal of this paradigm is to create cities that are not only livable and resilient, but also sustainable and environmentally friendly.

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