eMOTIONAL Cities

Mapping the cities through the senses of those who make them

DELIVERABLE 2.3

Final *e*MOTIONAL Cities Research Framework

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MICHIGAN STATE UNIVERSITY

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Executive Summary

Work Package 2 aimed to propose a conceptual methodology for subsequent work packages for the *e*MOTIONAL Cities project. The key objectives for WP2, as described in the original proposal, are as follows:

- Review and compile existing research and scholarship on the use of neuroscience to understand the relationships between urban environments and health
- Create the conceptual framework and overarching research questions
- Articulate the final research framework used in the study

The first tasks associated with this work package and presented in Deliverable D2.2 were as follows:

T2.1 – Identify the terminology to be used in the scoping reviews

T2.2 – Scoping review of urban environment and public health

T2.3 – Scoping review of neuroscience applied to urban environments

T2.4 – Compile results from scoping reviews to create research questions and conceptual framework

Previous deliverable D2.2 provided a comprehensive review of the current literature. The key tenants that should be observed in the subsequent development of methods and models are as follows:

- The model should be spatially and temporally nested.
- The model has no particular starting point to it as the flow depends on the needs of the participants, as well as the project.
- Solutions need to be community oriented as much as individually oriented.
- The project should be scalable in terms of individual level assessment/measures as well as neighborhood and community level ones, as these would take care of a variety of health needs simultaneously.
- Needs and assessments should be understood at the inter- and intra-generational levels.
- Combining different assessment and metric approaches (i.e., combining mixed and multimodal methodologies) leads to synergy and a more robust product.

Deliverable D2.3 Articulates the final research framework used in the project and addresses the final task associated with Work Package 2, namely:

- T2.5 – Critical thinking and linkage between urban environments, neuroscience and health

This report for D2.3 is presented in four sections. The first section presents the proposed conceptual framework, and main points that were to serve as guiding principles for the subsequent work packages and how the conceptual framework was used and adapted to create the final research framework. Section two outlines the significance of the conceptual framework, as well as adaptations, challenges, and key takeaways from selected WPs that conducted analyses or experiments. Section three draws on linkages between the urban environments, neuroscience and health or well-being. Finally, section four concludes by offering some preliminary insights for Urban Planners based on the relationships observed.

The *e*MOTIONAL Cities project relied on a mixed methods approach, combining qualitative and quantitative techniques – from data collection to data description, use and interpretation. It combined multidisciplinary instruments and analytical skills from three main fields: *Urban Planning and Design* – including spatial analysis and geographic information systems; *Neuroscience* – including behavioral, neuroimaging and clinical neuroscience; and *Data Science and Technology* – including big data analytics, machine learning and VR/AR. The project's methodology, segmented into WPs, shows that the knowledge generated from one stage is used as some form of input into the next stage.

This report does not present the details of what the subsequent WPs did in terms of methodology or their results; instead, it focuses on any deviations from the original conceptual framework and the main, overall impressions on the experiences of using the original conceptual framework as the guiding strategy for their work.

1. Conceptual to Final Research Framework

The *e*MOTIONAL Cities project stemmed from the understanding that the built environment played a significant role in mental and physical health. The premise was that more systematic evidence, and objective measures on how the urban environment relates to collective health and individual behaviour, were not well researched or assessed.

While small-scale applications of neuroscience have been undertaken by a handful of scholars[1] – typically in indoor, and controlled, environments (e.g., the impact of lighting or sound on people's moods), there is no comprehensive large-scale assessment of how urban environments impact public health as measured through brain activity. Such comprehensive knowledge is fundamental when evaluating or creating policies aimed to improve physical and psychological health-related behaviour and are also requisites to create sustainable and healthy cities.

Work Package 2 aimed to guide the project by conducting a comprehensive literature review, and proposing a conceptual framework that addressed multiple weaknesses found by other studies in the field. Methodologic Guidelines to incorporate two diverse fields of research: Urban Planning and Neuroscience were proposed.

Recap of the Conceptual Framework Presented in D2.2

The final research framework for this project is very closely aligned with the initial conceptual framework. Before discussing how the conceptual framework was adapted, it is important to present the salient features of the proposed conceptual framework. Understanding the main salient points for the initial framework is critical for the subsequent understanding of the adapted final one. Below are the main points for the original conceptual framework:

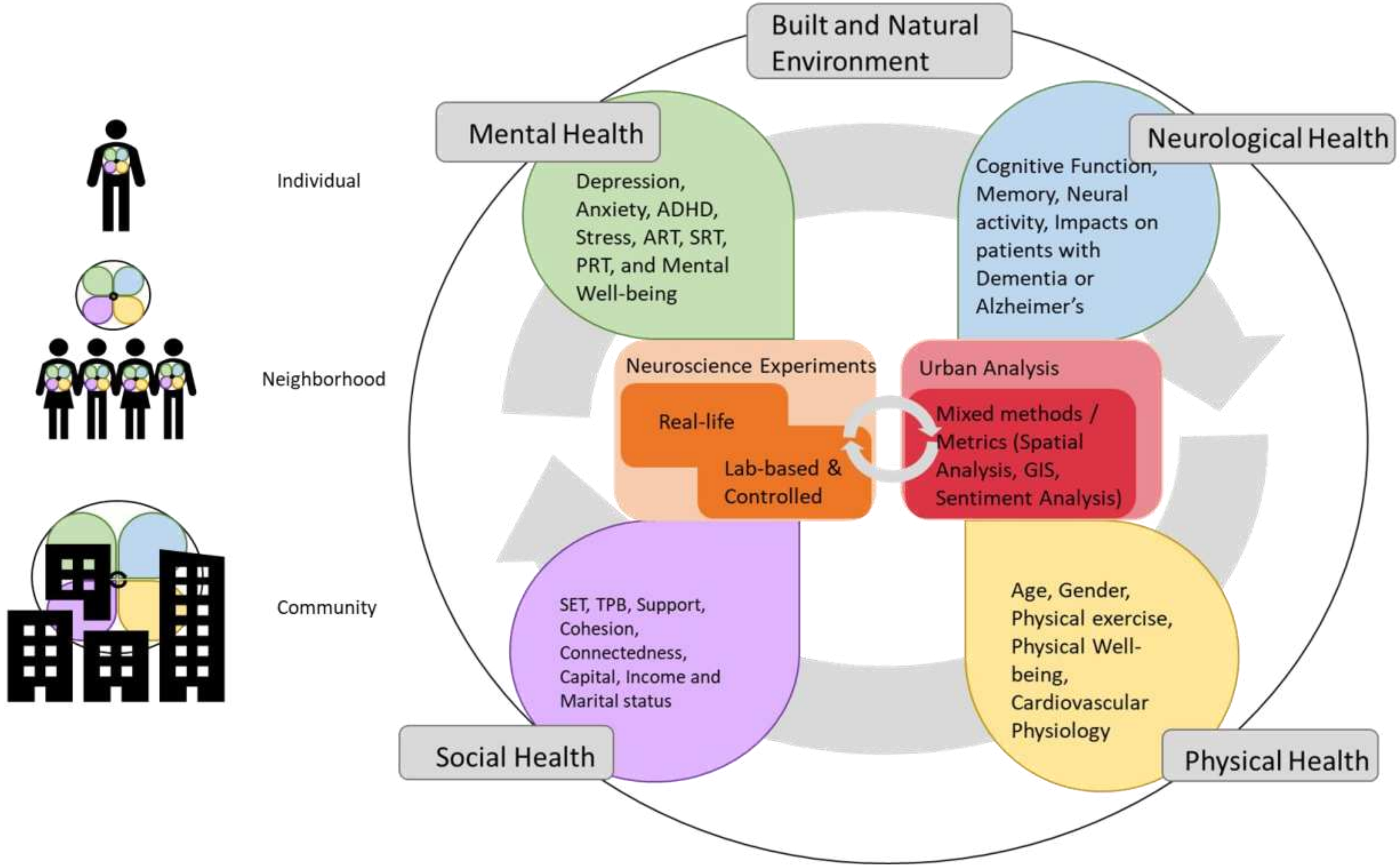
- ***The model should be spatially and temporally nested***. Incorporate multiple geography studies and include participants from multiple generations. This recommendation came from the limitation that spoke about *generalizability* and the lack of *temporal connections*.
- ***The model has no particular starting point as the flow depends on the needs of the participants, as well as the project***. Imbibe the notion that there is not a strict linear progression from start to the end, but rather elements flow concurrently feeding into each other and reinforcing learned aspects from experiments (Figure 1).
- ***Solutions need to be community-oriented as much as individually-oriented***. This recommendation came from the limitations with the availability, quality and subjectivity of the data. As such, we have included multiple levels of analyses in the project.
- ***The project should be scalable*** in terms of individual level assessment and neighborhood and community level ones as these address a variety of health needs

[1] See our systematic review linking urban studies and neuroscience research in https://doi.org/10.3389/fpsyt.2022.983352

simultaneously. This recommendation also came from the limitation that spoke to the quality or subjectiveness of the data, sample sizes and biases.

- ***Needs and assessments should be understood at the inter- and intra-generational level***. This recommendation came from the limitations that spoke about methodological concerns and quality of data collected. Much of the studies overall only focused on a specific type of population due to the difficulties with primary data collection; and essentially spoke to the need of collecting data on a wider population cohort with various socio-economic characteristics and abilities.
- ***Combining different assessment and metric approaches leads to synergy and a more robust product***. This recommendation stemmed from the limitations regarding methodology. Different assessments and measurements would be helpful making the project more robust. While previous studies have focused on one aspect of emotional perception or reaction to the built environment, more recent work have identified the lack of multiple approaches and subsequently self-selection in these studies.

Figure 1: Proposed Conceptual Framework



Use and Adaptations towards the Final Research Framework

All WPs aimed to honor the methods proposed, and link those back to the results and the proposed conceptual framework ideologies. Best practices of project implementation suggest a linear workflow where previous steps inform and educate subsequent steps of any project for consistency, continuity, and the ability to add new knowledge through the proposed project.

The eMOTIONAL Cities project employed a mixed-methods approach that integrated both qualitative and quantitative techniques, spanning data collection, description, utilization, and interpretation. It drew upon multidisciplinary tools and analytical expertise from three core fields: Urban Planning and Design—encompassing spatial analysis and geographic information systems; Neuroscience—covering behavioral and clinical neuroscience; and Data Science and Technology—including big data analytics, machine learning, and VR/AR. The project's methodology was structured into work packages, ensuring that insights gained at each stage served as inputs for subsequent stages—an essential practice for adhering to best practices in research and development.

Although the general methodology and conceptual framework were adhered to, extracting specific elements from the subsequent work packages and evaluating their relevance, key insights, challenges, policy implications, and potential future directions is essential.

- The project addressed varying scales: individual, neighborhood and community. The spatial analyses conducted in WP4 were at the neighborhood scale, while the experiments in WP5 were conducted at individual scales.
- The urban environment was extended to include both the built and the more natural spaces, as opposed to only the built environment, due to the preponderance of theories and evidence that both environments play a significant role in mental health. The experiments in WP5 specifically tested psychophysiological responses to subjects within urban built and more natural environments (as well as taking into account the population density).
- A critical aspect to study within the built and natural urban environments is mental health or well-being. Within this aspect, understanding from the *Attention Restoration* (ART), the *Stress Reduction* (SRT) and the *Psychological Recovery* (PRT) theories that were consistently mentioned in the literature review as being important to mental health were heavily utilized.
- Other factors, apart from the above-mentioned theories, would include depression, anxiety and stress as mental health factors to assess – given that they were the most often used key variables in the literature reviewed.

- The next aspect studied within the built and natural environments was social health. Here learning from the SET and TPB theories that impact behavior in various environments found in the literature were used.
- Other factors included were the socio-economic characteristics of income and marital status, and social characteristics of support, cohesion, connectedness, and capital as other key variables found in the literature reviewed. These characteristics were studied within the spatial analyses in WP4 and taken into account when interpreting the results from WP5 experiments.
- Physical health was the second most used category of variables found in the literature reviewed and included various factors such as physical activity and well-being. This aspect was carefully studied within the built and natural environments.
- Neurological health, cognitive function, memory, and impacts on people with MCI (mild cognitive impairment) were addressed. This is included as the lack of these factors was one of the main weaknesses mentioned in the literature reviewed.
- Assessments using spatial analyses at varying scales and indoor and outdoor neuroscience experiments were conducted. These multiple assessments form the basis of this robust study.

2. Most Significant Elements of the Methodological Framework to other Work Packages

The proposed research framework was crucial for all the work packages conducting analyses. WP4 (Spatial Analyses) utilized all framework elements to develop their work package. They ensured that the analyses at the city/regional level could be translated and used in subsequent work packages at the finer, individual level. WP4 also was conducted at various locations for a global view of differing built environment characteristics. Additionally, WP4 included relevant socio-demographic factors such as age and gender, and mental and physical health factors to reflect the inter- and intra-generational facets of the conceptual framework.

WP5 (Indoor and Outdoor Experiments) utilized scalability at the individual (e.g., contemplating individual fMRI and EEG responses) and community (for example, by using social media data) levels in the development of their first experiment. They also utilized temporal nesting and differing measurements in the development of experiments 2 through 5. Multiple assessment and measurement techniques were employed: using observational studies; measuring behavior and neural signals; considering healthy volunteers and a clinical group (consisting of elderly adults with mild cognitive impairment or MCI); and performing real-life or virtual/augmented reality (VR/AR) tasks (such as the navigation task of experiment 5). This ensured the attainment of the aim for scalability, generalizability, and methodological robustness from the conceptual framework. Adding various levels of green/natural urban environments as suggested in the conceptual framework, allowed WP5 studies to reflect on a full scale of city spaces.

Work Packages 6 and 7 focused on the insights from the analysis of data collected in the previous work packages and their scalability in robust decision-making. Although these work packages did not perform any experiments, they used the results from previous work packages and created scenarios, and aimed for effective generalizability of results.

Adaptations by other WPs

Most subsequent WPs did not make any significant adaptations or changes to their work. WP4 synchronized their work with that of the WP2 results, and WP7 used a neighborhood focused framework to showcase scenario discovery. WP5 found multiple points through utilizing the framework. Scalability brought up correlations between certain global versus individual measures that confirm the possibility of using a combined approach (See full write up for examples from experiments 1 and 2). Utilizing a spatial and temporally nested view led to experiment 1 revealing urban features that elicit emotional or reward responses that are generic across individuals. Experiment 2 highlighted that relationships between urban nature and emotional response could be influenced by population density. Additionally, WP5 found that multimodal data collection was key to provide a comprehensive human-environment assessment, reinforcing known information to overcome limitations in outdoor data collection, and in supporting the construction of better models.

Challenges encountered by subsequent WPs

The most prominent challenge in work packages 4, 5, and 7 was related to data. WP4 noticed the challenge with data availability within different geographical contexts (countries and cities). WP5 faced challenges in the form of difficulties integrating general vs. individual data. This led to some issues in conducting analysis, interpretation, and visualization while attempting to respond to the research questions. The team also faced difficulties analyzing spatially nested gaze data because of its variability from person to person. There was also physiological variability based on outdoor experiment weather (which was not possible to control across all participants). Finally, WP5 found disparities between self-reported and the physiological or neurological objective findings. This not only has led to doubts, but it has also highlighted the importance of a multimodality approach.

WP7 experienced challenges in insuring models from previous work packages and generated reliable, and computationally efficient, data. Additionally, WP7 noted that all limitations to models limited policy rationales. They experienced limitations with their ability to model the data due to the large and complex models required to do so. The partners noted that the project could have benefitted from a targeted activity on the transformation of specific policies and their targets to the data analysis itself (i.e., exploration vs exploitation data analysis).

Constructive findings by subsequent WPs

There were several constructive findings listed by the partners who worked on subsequent work packages. WP4 found it useful and interesting to bring students across different levels onto the project, which helped with getting a diversified perspective of the analyses being conducted. WP5 found (with the success of experiment 1) that neurobiological principles could be applied to urban science – somehow supporting a proof of principle for the emerging field of *Neurourbanism*[2]. They also had some unexpected findings that revealed certain challenges such as the fact that individual level data was not always correlated with aggregate data and that outdoor EEG data collection in Lansing, Michigan was complicated by interference from strong electrical fields. WP7 noted that quality-diversity algorithms should be further explored in robust decision-making due to the early experiments showing promising results.

Significant policy implications from subsequent WPs

WP4 called for the development of a methodology that could be applied across scales and promoted the use of both qualitative and quantitative data analysis. They also noted

[2] https://doi.org/10.1016/S2215-0366(16)30371-6

that hyper-localized analysis produces interesting neighborhood-level patterns. WP5 identified certain features of urban spaces that interact with the human brain systems of emotion and reward processing. They also found that these interactions depend on population density. WP7 found that their work supports model-based decision making in urban planning processes.

Future research directions

There were several areas of future research and development identified by partners from some of the work packages. WP4 and WP5 stated that further data integration and research with new or additional spatial health metrics would be useful. For example, is there a significant pattern for certain groups of people (with more stress, depression, or anxiety, or as a function of personality traits) and the urban environment? It was also noted that population density at various types of city locations could be explored in relation to the perceived experience of an urban space's qualities. Lastly, partners from both work packages 5 and 7 mentioned the potential for further development of tools and technology to better analyze urban spatial and human response data together (including the potential usage of AI tools), and the optimization of the prototype backpack wearable kit of both physiological and microclimate sensors.

3. Key linkages between urban environments and public health

The connection between emotional health and the built environment is increasingly being understood through a neurological lens, shedding light on how the physical spaces we inhabit influence brain function, mood, and well-being. Our study reinforces and highlights the linkages below:elow are some key linkages observed in our studies:

1. Environmental Stressors and the Brain

The built environment can either alleviate or exacerbate stress, a key determinant of emotional health. Crowded spaces, high noise levels, poor air quality, and limited access to nature (either green or blue) have been shown to elevate cortisol levels and disrupt brain regions like the amygdala and prefrontal cortex, which regulate emotions and stress responses.

Conversely, environments with restorative aesthetics, lower noise pollution, and green/blue spaces foster relaxation and reduce neural hyperactivation related to stress.

2. Neuroplasticity and Environmental Design

The brain's capacity for neuroplasticity (its ability to adapt and, in certain cases, rewire) responds directly to sensory stimuli in the built environment. Natural light, textured materials, biophilic design elements, and spatial layouts that encourage movement and social interaction can positively influence neural pathways associated with emotional resilience and cognitive function.

For instance, daylight exposure has been found to regulate the brain's circadian rhythms, improving mood and reducing symptoms of depression.

3. Nature and Emotional Regulation

Access to green spaces, parks, and vegetation-rich environments is strongly linked to improved emotional health. Neurological studies show that exposure to more nature-based environments enhances activity in the brain's default mode network, associated with introspection and emotional regulation, while dampening activity in areas linked to rumination and anxiety.

Our study found that green spaces, when crowded, lose their positive emotional influence, as people are the main attractor factor and therefore the first element to firing our brain. We have also found thresholds, for instance, certain spatial layouts require more, or less, greenness to trigger the same positive responses. Or, that certain levels of complexity are good, but above a certain threshold they have a negative effect, firing high levels of stress.

Urban planners focusing on restorative environments aim to integrate nature as a tool for improving mental well-being at the community level.

4. Spatial Perception and Social Connectivity

Neurological research highlights that built spaces affect how individuals perceive themselves and connect with others. For example, public spaces that promote natural gathering points—such as plazas, shared workspaces, or well-designed public transit systems—activate brain regions associated with social bonding, reduce loneliness and promote positive emotions.

However, poorly designed spaces that hinder movement or isolate individuals can lead to heightened feelings of disconnection, negatively impacting emotional health.

5. Neurological Responses to Color and Aesthetics

Color, patterns, and visual cues in architecture evoke specific emotional and neurological responses. Warm colors, for example, activate arousal regions in the brain, fostering energy or anxiety, while cooler tones encourage calmness. The built environment's aesthetics, including proportions, symmetry, and even acoustics, also influence neurological states that underpin emotional health.

6. Trauma-Informed Urban Design

Through a neurological lens, spaces designed to mitigate triggers for trauma—such as crowded or poorly lit areas—can reduce amygdala hyperactivity in individuals with post-traumatic stress or anxiety disorders. Trauma-informed design principles incorporate features like clear sightlines, accessible pathways, and calming sensory inputs, creating environments that support emotional healing.

Linkages between the built environment and people with mild cognitive disorders

The built environment plays a significant role in the quality of life, independence, and safety of people with mild cognitive disorders or dementia. By prioritizing user-centric design and addressing the unique needs of individuals with cognitive impairments, the urban built environment can enhance their well-being, independence, and ability to participate actively in society.

1. Cognitive and Navigational Challenges

- **Wayfinding difficulties**: People with dementia often struggle with navigation due to memory loss and impaired spatial orientation. Poorly designed spaces with complex layouts, lack of clear signage, or inconsistent visual cues can increase confusion and anxiety.
- **Familiarity**: Environments that feel familiar and intuitive reduce stress and support better wayfinding. Incorporating recognizable landmarks and maintaining consistency in spatial layouts can help.

2. Impact on Safety

- **Trip hazards**: Uneven surfaces, clutter, and poor lighting can increase the risk of falls, which are a common concern for individuals with cognitive impairments.
- **Accessibility**: Barriers like narrow doorways, stairs without railings, or inaccessible bathrooms can limit mobility and independence.
- **Wandering risks**: Open or unsecured layouts can lead to wandering, a common behavior among people with dementia, putting them at risk of getting lost or injured.

3. Psychological Effects

- **Sense of control**: Well-designed environments promote autonomy by enabling individuals to perform daily tasks with minimal assistance.
- **Overstimulation**: Excessive noise, clutter, or overwhelming visual stimuli can trigger agitation or confusion. Conversely, calming environments with appropriate lighting, acoustics, and organization can reduce stress.
- **Social isolation**: Poorly planned spaces may discourage social interaction, while environments designed for gathering and interaction can foster a sense of community.

4. Support for Cognitive Function

- **Natural light**: Exposure to daylight helps regulate circadian rhythms, improving sleep and overall well-being. Poor lighting can exacerbate disorientation or cause visual misinterpretation of environmental stimuli.
- **Green spaces**: Access to nature and outdoor areas has been shown to reduce stress, improve mood, and encourage physical activity in individuals with cognitive impairment or dementia.
- **Memory aids**: Incorporating features like color-coded spaces, personalized signage, or visual prompts can support memory and orientation.

4. Conclusion and Insights for Urban Planning

Our findings aim to increase the awareness of health in urban planning field and policies as these findings also align very well with the WHO framework of Health. These findings can be used to inform **neuroscience-driven urban planning** strategies. Examples include:

1. **Incorporating Nature**:
   Prioritize **green spaces** like parks, urban forests, and tree-lined streets to stimulate the brain's **reward circuits**. These spaces create environments people are naturally drawn to, enhancing both mental well-being and social cohesion.
      Example: Adding pocket parks or rooftop gardens in dense urban neighborhoods.

2. **Creating Aesthetic Appeal**:
   Design streetscapes with attractive facades, architectural variation, and public art to create environments that visually engage the perception and reward systems.
      Example: Use vibrant, non-linear designs in commercial areas to reduce monotony and stimulate positive emotional responses.

3. **Walkability**:
   Develop walkable environments with mixed-use spaces to promote physical activity, accessibility, a more active lifestyle, and exploration, as well-connected areas are linked to higher emotional satisfaction.

4. **Urban Green Networks**:
   Create **connected green corridors** within cities to ensure residents have access to nature within walking distance. Green spaces should be evenly distributed to ensure equity in mental health benefits.

5. **Noise Reduction Strategies**:
   Plant trees and install green walls to reduce noise pollution, which EEG studies associate with higher stress levels, but also to purify the air and mitigate heat waves effect.

6. **Integrating Green Spaces with Active Design**:
   Combine green spaces with pedestrian and cycling paths to encourage physical activity, which further enhances mental health.
      Example: Incorporating walking trails in urban parks to promote relaxation and social interactions.

7. **Mixed-Density Development**:

Plan for a mix of low-, medium-, and high-density neighborhoods to avoid overstimulating environments that may lead to stress. Ensure that high-density areas include ample natural and social spaces to counterbalance their intensity.

Example: In dense urban cores, integrate community plazas or rooftop green spaces to provide relief.

8. **Zoning for Emotional Well-Being**:
   Introduce zoning regulations that limit extreme sensory overload caused by features like high noise levels, lack of greenery, or excessive lighting.

   Example: Develop quieter residential zones adjacent to public green spaces, minimizing urban stress while retaining accessibility to amenities.

9. **Testing Design Prototypes with VR**:
   Urban planners can use **VR environments** to simulate proposed urban designs and evaluate their effects on emotional health using eye tracking, EEG and other physiological sensors (for heart rate or galvanic skin responses).

   Example: Simulate pedestrian experiences in proposed city centers to ensure they evoke positive emotional responses (e.g., calmness, engagement).

10. **Improving Public Participation**:
    VR-based simulations allow communities to experience future designs and provide feedback, creating designs that reflect user needs and emotional health considerations.

    Example: Use VR headsets during public consultations to showcase urban renewal projects and ensure restorative and engaging designs.

11. **Architectural Features Testing**:
    Use VR to analyze how specific architectural elements (e.g., curved lines, open spaces, textures) affect neural responses before construction begins.

12. **Stress Buffer Zones**:
    Identify urban hotspots with high amygdala activity (e.g., crowded intersections, transit hubs) and integrate calming design features like natural barriers, soothing color schemes, or acoustic buffers.

13. **Sensory Optimization**:
    Limit overstimulation in urban settings by regulating noise levels, reducing visual clutter, and designing spaces with clean, simple lines and layouts.

    Example: Designing metro stations with noise-dampening materials and greenery to reduce stress in transit areas.

14. **Lighting Design**:

Optimize urban lighting to avoid overstimulation, ensuring public safety without harsh, disruptive lighting that can increase stress. Soft, warm-toned lighting has been associated with relaxation.

15. **Targeted Interventions in Underserved Areas**:
    Ensure that all socioeconomic groups benefit from access to green spaces and well-designed environments. Studies show that lower-income communities are disproportionately exposed to stress-inducing urban environments.

16. **Data-Driven Decision Making**:
    Use neuroscience tools like EEG and fMRI in urban planning to identify populations most affected by poor design and prioritize interventions.

Recommendations for Urban and Building Design specifically for people with mild cognitive impairments:

Dementia-friendly design: This approach emphasizes simplicity, safety, and familiarity. Key principles include clear sightlines, non-slip contrasting flooring, and minimizing unnecessary changes in the environment.

Calm color schemes: Using soft, neutral colors can create a soothing atmosphere, while avoiding bold patterns that may confuse or disorient individuals.

Sensory engagement: Design elements that stimulate the senses, such as textured surfaces or areas with gentle sounds (e.g., water features), can have positive effects.

Public spaces: Ensure urban areas are accessible and easy to navigate with clear signage, consistent design, and safe pedestrian routes.

Community centers: Design spaces that encourage engagement and activity, such as gardens, recreational rooms, and sensory-focused areas.

The proposed conceptual framework was used as a guide by the subsequent work packages to conduct the relevant studies and generate results. This document does not lay out the details of the studies done by each work package as their methodologies and results have been reported in their deliverables. This document, in turn, emphasizes that the subsequent work packages that conduct experiments and analyses have used the conceptual framework as a guiding document to incorporate various facets to ensure a robust implementation of the project.

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