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RESEARCH ARTICLE

Development of an urban health and wellbeing index for work precincts: A comparative study in Sydney, Australia

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Abstract Work precincts are recognized for their significant role as generators of employment and associated commerce within urban areas. This study describes a method for analyzing the physical characteristics of urban work precincts in promoting the health and wellbeing of their occupants. The following physical parameters are analyzed: public transport accessibility, green and blue spaces, food environments, fitness facilities, supermarkets, and grocery stores. The parameters are assessed using quantitative spatial analysis based on street network data, as well as point of interest data acquired from OpenStreetMap (OSM). The streets and their intersections are stored in the OSM database as links and nodes, respectively. The evaluation of the performance metrics involves measuring the street network distance from each node to the closest node of interest for each parameter. The metrics are then combined, forming an urban health and wellbeing index (UHWI), which can be used to compare the performance of different precincts. The method was tested by investigating four work precincts in Sydney, Australia, all hosting a large office building belonging to the same business institution. Our results identified two of the four precincts with a high UHWI and resulted in the identification of one underperforming precinct.

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1. Introduction

Multiple studies have shown that the physical design and configuration of the urban environment and the distribution of amenities affect health and wellbeing. Parameters such as the presence of green and public open spaces have been linked to stress restoration (Kaplan and Kaplan, 1989; Hedblom et al., 2019; Barton and Rogerson, 2017; Kondo et al., 2018) and increased levels of physical activities (Giles-Corti et al., 2005). The reduced presence and insufficient distribution of amenities related to health, wellbeing, and other parameters affecting the quality of life can lead to unequal opportunities (Du et al., 2021) and can increase existing inequities (Akhavan et al., 2018).

Although a significant progress has been observed in the development of methods for mapping walkability (Giles-Corti et al., 2014) and other aspects related to health, most studies have focused on residential neighborhoods (Hoehner et al., 2013; Johnson, 2012; Cain et al., 2018). Considerably less effort has been devoted toward understanding the distribution of spatial determinants of health and wellbeing in other environments that individuals visit for work or leisure. A limited number of studies have been conducted on the capacity of workplace neighborhood in promoting health and wellbeing (Badland et al., 2014a; Gilchrist et al., 2015; Gritzka et al., 2020; Hoehner et al., 2013; Marquet et al., 2018). These studies provide evidence that reduced accessibility to services and amenities related to health and wellbeing in the workplace is associated with negative health effects (as is discussed in detail in Section 2.1). However, methods and tools that will allow researchers, urban designers, and planners to understand which work precincts underperform with regards to the presence of built environment characteristics that promote health and wellbeing are lacking. Furthermore, the studies that were examined (presented in detail in Section 2.1) typically focused only on one among the multiple relevant parameters, as the objective was to show the association between that parameter and health and wellbeing outcomes. The simultaneous analysis of different relevant factors would have the advantage of providing a comprehensive assessment of a precinct's capacity to promote a healthy lifestyle. Without such a multidimensional approach, performing a comparative analysis at a city level and prioritizing interventions in areas that are at a significant disadvantage will be difficult. Although methods and tools that allow the analysis of multidimensional problems are available, applications that focus explicitly on the multidimensional analysis of spatial parameters that promote a healthy lifestyle, especially in the context of work precincts, are lacking.

In this context, this study outlines a method for analyzing the capacity of urban work precincts to promote health and wellbeing based on the physical characteristics and features of the built environment. This study focuses on urban work precincts, referring to urban areas that individuals visit regularly for work purposes, provide diverse employment opportunities, and enable economic functions to occur. The method is based on understanding the spatial determinants of urban health by studying their geographical distribution. It involves extracting relevant parameters from freely accessible OpenStreetMap (OSM) data and evaluating them using geospatial analysis techniques. The performance per metric of a studied area is initially calculated separately using distance-based analysis and is subsequently combined to create an urban health and wellbeing index (UHWI). The UHWI is proposed as a metric that can be used to compare different areas with respect to their capacity to enhance and support the wellbeing of their employees. The method is tested by applying it to compare four urban precincts that host offices of the same organization.

The significance of the proposed method lies in its capacity to perform a comprehensive evaluation of spatial features and then overlay them to reveal opportunities and barriers while providing a score for urban health and wellbeing. By using the developed UHWI, the advantages and disadvantages of different work precincts can be easily communicated with multiple stakeholders, such as environmental planning agencies, urban designers, commercial institutions, and policymakers.

The paper is organized as follows. Section 2 presents relevant literature that supports the selection of the parameters related to health and wellbeing. It also outlines the methods used for the quantitative analysis, and it then presents the urban areas selected for the practical application of the method. Section 3 presents the results of our analysis and the extracted UHWI for the examined precincts. Section 4 subsequently discusses the outcome of the spatial analysis, and Section 5 presents the conclusions and suggests future research avenues.

2. Material and methods

The starting point of this study, which was conducted within the Australian context, is the review of relevant local frameworks and guideline documents, namely, the Healthy Built Environment Checklist (New South Wales (NSW) Ministry of Health, 2020) and the Blueprint for an Active Australia (National Heart Foundation of Australia, 2019). The Healthy Built Environment Checklist is vital considering the urban context in NSW, where this study was developed, deployed, and tested. The checklists' primary goal is to help build the capacity of health professionals to provide valuable feedback to local councils and other relevant organizations on health issues in relation to urban development plans and proposals specific to NSW. It is intended to facilitate strengthened partnerships and collaboration between health professionals and urban planners to promote healthy communities and is thus deemed highly relevant for this study. Similarly, the Blueprint for an Active Australia document has been developed by the Heart Foundation of Australia and leading experts on physical activity. It critically addresses Australia's major public health problem concerning physical inactivity. Both documents are deemed credible and, more importantly, relevant to the Australian built environment and social context, thereby providing a strong basis for the extraction of contextually embedded parameters for this study. An intensive review of these documents led to the identification of potential positive health influences (such as the promotion of physical activities, stress restoration, and the promotion of healthy food habits) resulting from built environment interventions. The following parameters were successively selected as influential factors to support an active lifestyle:

- *Public transport accessibility*
- *Green space*
- *Blue space*
- *Food environments*
- *Fitness facilities*
- *Supermarkets and grocery stores*

The targeted selection of these parameters was also dependent upon their relevance in the context of a work precinct. For instance, the proximity to medical and cultural facilities was determined as a parameter that would be of more importance in the context of analyzing the residential neighborhood of a worker and was thus not included in this analysis of the work precinct. Other criteria for the parameter selection were the following: the avoidance of overlap between the different parameters, their ability to be related to urban elements and features that are measurable via OSM data sources, and their capacity to be evaluated using accessibility (distance-based) analysis. The use of OSM data is a critical element in this study because it adds to the scalability and ease of adoption of the method proposed in this study.

Section 2.1 presents the key findings of extensive literature reviews that led to the selection of the parameters. Section 2.2 then elaborates upon the developed method for the analysis and extraction of the UHWI, and Section 2.3 describes the context of the practical application and testing of the deployed method.

2.1. Theory: parameters influencing urban health and wellbeing

2.1.1. Public transport

Multiple studies have shown that the strong presence of a public transport network encourages the use of public transport and increases the time spent walking. The Healthy Built Environment Checklist (NSW Ministry of Health, 2020) defines the presence of public transport stops within 400 m (for bus stops) to 800 m (for train stations) as a desirable criterion for proposed developments. Badland et al. (2014a) showed that the presence of public transport options within these distances from the workplace increases the chance of using public transport to commute to work. This feature thus appears frequently as an important criterion in walkability studies. For instance, Higgs et al. (2019) used the parameter *access to daily living services* in the calculation of a walkability index; this parameter measures the ability to reach necessary services (e.g., public transport stops, supermarkets, and convenience stores) by foot by assessing their presence in the analyzed neighborhood (within 1600 m).

2.1.2. Presence of green and blue spaces

The Healthy Built Environment Checklist (NSW Ministry of Health, 2020) advocates for workplaces being located close to stress-relieving environments to provide quality employment. The psycho-evolutionary theory of stress reduction (Ulrich et al., 1991) also supports this suggestion and states that the presence of natural elements, such as green and blue spaces, is one of the key characteristics that assist in stress restoration. Connecting building occupants to natural environments (also known as biophilic design) also elicits fascination and a feeling of "being away," which are key qualities in the attention restoration theory of Kaplan and Kaplan (1989).

Several studies have shown that exposure to natural environments can elicit positive psychological responses and reduce stress and anxiety. However, similar to other parameters, previous studies have focused more on the restorative properties of green and blue spaces close to residential rather than workplace settings. A limited number of recent studies have focused on the workplace. Gritzka et al. (2020) reviewed studies on the effect of nature-based interventions in the workplace and found positive associations with cognitive ability and mental health indices. Gilchrist et al. (2015) showed a positive association between wellbeing and physical and visual access to green spaces around the workplace. The study also showed that individuals with higher levels of job stress tend to spend more time in outdoor green spaces close to work. Lottrup et al. (2013) also showed that physical and visual access to a green outdoor environment in the workplace is associated with a positive workplace attitude, with male participants displaying decreased stress levels. Some studies have also reported that the presence of blue space might be an important element that assists in stress restoration (Karmanov and Hamel, 2008; Korpela et al., 2015; Wang et al., 2019). Korpela et al. (2015) recommended breaks for viewing and visiting areas with natural vegetation and water elements during the workday. Large water bodies, such as rivers, lakes, and waterfronts, may also have a higher ability to generate a feeling of fascination, which is a significant element of stress restoration theories, as previously mentioned. The type of the assessed water element differs among studies. For example, Kaplan and Kaplan (1989) argued that all types of water have restorative effects, whereas some more recent studies have an explicit focus on the effects of large water bodies, such as rivers and canals (Karmanov and Hamel, 2008; Korpela et al., 2015).

Similar to the aforementioned research findings, the Healthy Built Environment Checklist (NSW Ministry of Health, 2020) also mentions the equitable location of open spaces as an essential element for the promotion of physical activities. Giles-Corti et al. (2005) showed that increased access to public open spaces is associated with higher levels of walking. They highlighted that the size and attractiveness of the space also mattered, showing that providing an equitable distribution of public open spaces is insufficient if their characteristics do not encourage physical activities.

Other features related to open spaces, which are mentioned as important for the promotion of healthy living (NSW Ministry of Health, 2020), include the connection of public open spaces to public transport and the pedestrian and cycling network, the provision of adequate seating and lighting, the distance from traffic, the consideration of parameters related to safety such as visibility from outside, the inclusion of amenities and features that promote activity, and the provision of adequate space for the organization of festival and events.

2.1.3. Supermarkets and grocery stores

According to the Healthy Built Environment Checklist (NSW Ministry of Health, 2020), the presence of a range of land uses and facilities that attract activities and services the community need for the creation of healthy communities, as they promote social interaction and increase community safety and security. Many theorists (e.g., Jacobs (1961) and Montgomery (1998)) have pointed out that mixed-use is connected to neighborhood vibrancy and promotes walkability. Equitable access should thus be provided to facilities such as shops, health services, and recreational and leisure areas.

Supermarkets and grocery stores play a critical role among other uses and facilities that can assist in the promotion of urban health and wellbeing. This idea has been highlighted in walkability studies (Higgs et al., 2019), as supermarkets and grocery stores are considered services related to daily living, and their presence in proximity encourages walking instead of using the car. This parameter is also significant for the promotion of healthy food habits, which will be discussed in Section 2.1.4.

2.1.4. Food environments

The availability of healthy food options around the workplace and residential environments is a critical component for the promotion of healthy food habits and the reduction of health risks. The Healthy Urban Development Checklist mentions the presence of healthy food outlets such as supermarkets and grocery stores close to residential locations (within 400—500 m) as a parameter that can lead to increased consumption of fruits and vegetables and a reduction of obesity risks (NSW Ministry of Health, 2020). Workplace food environments have been considerably less studied compared with residential environments (Thornton et al., 2013); however, some recent studies have showcased their importance. The study of Thornton et al. (2013), for example, which focused on women, showed a positive association between healthy food consumption and the presence of healthy food options near workplaces. Another study by Watts et al. (2016), which focused on young adults, also found that the exposure to healthy food options around the workplace was connected to lower obesity rates. Adlakha et al. (2015) also showed that the presence of healthy restaurants around workplaces was positively associated with physical activities for leisure and travel purposes.

2.1.5. Fitness facilities

According to the Healthy Built Environment Checklist (NSW Ministry of Health, 2020), the presence of outdoor gym and training equipment is connected to increased physical activities and promotes social interaction. The presence of private sports and fitness facilities is also essential in residential or workplace neighborhoods. Edmunds et al. (2013) showed that the lack of sports facilities close to the workplace may act as a barrier to physical activities. Hoehner et al. (2013) also found that the number of private fitness facilities within 800 m from the workplace is associated with higher cardiorespiratory fitness.

2.2. Description of the method

After presenting the literature that supports the parameter selection, this section discusses how each parameter is analyzed to calculate the UHWI. Table 1 presents an overview of the parameters underpinning urban health and wellbeing, which are combined to form the UHWI. Sections 2.2.1 and 2.2.2 explain the process of data acquisition and calculation of each parameter in detail, and Section 2.2.3 explains the process of combining the analyzed parameters to extract the UHWI.

2.2.1. Data acquisition

The developed method is based on acquiring and analyzing freely accessible OSM data using the *osmnx* Python library. This data source contains street network data, as well as point of interest (POI) data. The streets and their intersections are stored in the OSM database as links and nodes, respectively, along with topological information regarding their connections. The OSM links correspond to

Table 1 Overview of the parameters assessed for calculating UHWI.

Assessed parameter	Health & Wellbeing impact	Type of analysis	Measurement unit
Public transport accessibility	Promotion of physical activity	Distance from closest public transport option	m
Green space	Stress restoration, promotion of physical activity	Distance from closest green space	m
Blue space	Stress restoration	Distance from closest blue space	m
Supermarkets and grocery stores	Healthy food habits, promotion of physical activity	Distance from closest supermarket/grocery store	m
Food environments	Healthy food habits, promotion of physical activity	Distance from closest food environment	m
Fitness facilities	Promotion of physical activity and social interaction	Distance from closest fitness facility	m

street segments, and the nodes refer to street intersections. The nodes may also include points where the street segments curve; however, these are removed for the purpose of this study by simplifying the network and consolidating the nodes that are extremely close to each other (see Section 2.2.3). The geotagged POI data include locations identified as interesting or useful by users; such locations include landmarks, parks, retailers, restaurants, and cafés and generally instances of non-residential land use. POI data have been used extensively as indicators of the spatial distribution of land use types in past studies, which involve the analysis of land use density or diversity (Yue et al., 2016).

The analysis of each precinct is conducted by selecting the central point according to the research context. For instance, in the case studies presented in Section 3, the central point is the studied business institution. Then, relevant OSM data are extracted for all the street network nodes within the neighborhood (the area within 800 m from the center, corresponding to a 10-min walking distance). Data are also retrieved for an additional buffer of 1600 m around the boundaries of the neighborhood to allow the computation of relevant parameters at the points that are close to the boundaries. Thus, the analysis is conducted at the neighborhood scale (the area within 800 m). The choice of this distance is based on similar studies focused on workplaces (Hoehner et al., 2013) and considering 10 min (time needed to traverse 800 m) as a reasonable walking distance in the context of this study. Only the parts of the street network that allow walking are used (excluding paths that are exclusively used by vehicles).

2.2.2. Calculation of the performance metrics for each parameter

The method used to evaluate the performance metrics involves measuring the distance from each node to the closest node of interest for each metric. The distance, in this case, is defined as the street network distance (the actual distance that a pedestrian must cover to reach a destination). The graph presented above (Fig. 1; the distances in the figure are exaggerated for demonstration purposes) shows an example of measuring the distance from each node to the closest park and the demarcation of colors to the nodes accordingly.

Distance-based analysis is selected over other metrics (e.g., number of reachable parameters) as it reflects the time needed to reach each facility, and it is more suitable for assessing if an equitable distribution of amenities exists in the analyzed area. If a large number of amenities (e.g., public transport stops) are present in a neighborhood but are concentrated in one area leaving the rest of the neighborhood underserviced, then distance-based analysis can reveal this disparity. The floor area of reachable parameters is also reflected in the results of distance-based analysis, because the number of nodes that have a short distance from the boundaries of an analyzed parameter increases when its floor area is large.

The process of calculating the separate performance metrics is the same for each parameter. First, relevant POI data are acquired, and the distance from each node to the closest relevant POI is then measured. For instance, the parameter *distance from the closest public transport option* is calculated by querying the OSM database to obtain POIs related to public transport and then finding the distance from each node to the closest public transport node.

If the OSM data include green spaces that are marked as private, then they should be excluded from the analysis. The blue spaces that are analyzed include any type of still or flowing water. For the calculation of the *distance from the closest food environment*, the relevant POIs are initially sorted into three categories (i.e., cafes, restaurants, and fast food) based on their OSM tags. Fast food retailers are subsequently excluded from the overall dataset of food environments to remove the unhealthy food retailers following the literature presented in Section 2.1.4, and the parameter *distance from the closest food environment* is calculated by measuring the distance from each node to the closest food option.

2.2.3. Calculation of UHWI

After calculating the aforementioned parameters, the UHWI is computed for each work precinct. UHWI is a score expressing the performance of the chosen parameters with respect to urban health and wellbeing. The UHWI analysis

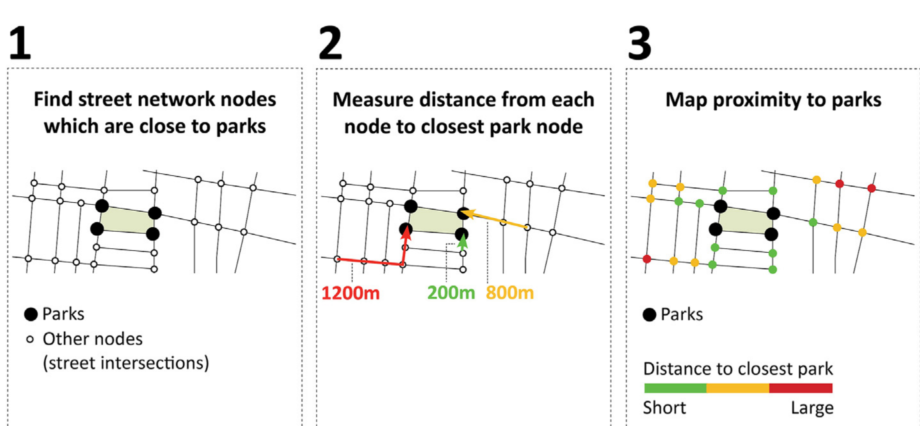

Fig. 1 Method used for parameter evaluation.

STREET NETWORK NODES BEFORE THE SIMPLIFICATION

STREET NETWORK NODES AFTER THE SIMPLIFICATION

Fig. 2 Street network nodes before and after the simplification.

involves calculating a score for each node and extracting descriptive statistics that show the performance of the precinct based on all nodes. The score extracted at the node level is calculated by considering the following parameters:

- T = Distance from the closest transport option
- G = Distance from the closest green space
- B = Distance from the closest blue space
- R = Distance from the closest food environment
- S = Distance from the closest supermarket and grocery store
- F = Distance from the closest fitness facility

The street network is initially cleaned from redundant points before the calculation of the index. This procedure leads to merging clusters of nodes that are remarkably close to each other by replacing them with their centroid, resulting in a cleaner approximation of the network (Fig. 2). The simplification happens only for nodes that are within 80 m of another node and are not significant elements of the street network (intersections or dead ends); the deleted nodes are thus points that are usually created in OSM to indicate the presence of curves within a street segment. This procedure is necessary to ensure that the extracted descriptive statistics are not skewed by the presence of multiple points, which refer to the same street intersection.

Then, a separate score ranging from 0 to 1 is assigned to each node (n_i) of the examined precinct for each parameter (e.g., T_i and G_i). The score (T_i, $G_{i,}$ …) for each node is given based on the following formula:

$$\text{score} = 1 - \frac{\text{Distance}_{\text{ni}} - \text{Distance}_{\text{min}}}{\text{Distance}_{\text{max}} - \text{Distance}_{\text{min}}},$$

where $\text{Distance}_{\text{ni}}$ is the distance from the node to the examined parameter, $\text{Distance}_{\text{max}}$ is equal to 1600, and $\text{Distance}_{\text{min}}$ equals 0. The formula essentially applies a min-max normalization, transforming the distance from the node to the examined parameter to a decimal between 0 and 1. The score is also subtracted from 1, such that the highest score is given to nodes that have the shortest distance from the parameter. $\text{Distance}_{\text{max}}$ is set to 1600 m, reflecting a maximum acceptable walking distance of 20 min from the parameter. To illustrate how the formula works, a node that has a distance of 200 m from the closest green space has the following score for parameter G:

$$G_i = 1 - \frac{200 - 0}{1600 - 0} = 0.875.$$

The scoring system, therefore, reflects the time needed to reach the examined parameters. The following list illustrates how the formula works by showing possible scores based on the distance between the node and the analyzed parameter:

- (Highest) Score = 1: The parameter is immediately reachable ($d \leq 1$ m).
- Score $\geq$0.875: The node is within 2.5 min from the parameter ($d \leq 200$ m).
- Score $\geq$0.75: The node is within 5 min from the parameter ($d \leq 400$ m).
- Score $\geq$0.5: The node is within 10 min from the parameter ($d \leq 800$ m).
- Score $\geq$0.25: The node is within 15 min from the parameter ($d \leq 1200$ m).
- (Lowest) Score = 0: The node is not within 20 min from the parameter ($d \geq 1600$ m).

The UHWI is then calculated by finding the geometric mean of the parameters for each node (n_i). The geometric mean of a set of n values is calculated by finding the nth root of their product. In this case, the formula is as follows:

$$\text{UHWI}_{\text{i}} = (T_i \times G_i \times B_i \times R_i \times S_i \times F_i)^{\frac{1}{6}},$$

where G_i, T_i, … are the scores for each of the examined parameters for this node. Given that the formula includes the calculation of the product of the separate scores, no value should be equal to 0. To prevent this from happening, if a node has a distance larger than 1599 m from a parameter, a value correction is applied, setting Distance_{ni} to

1599, which results in a score (e.g., T_i) of 0.0006 for this parameter. The resulting UHWI score is thus again a decimal between 0.0006 and 1.

Descriptive statistics are subsequently generated for each precinct. The resulting median and standard deviation values of the UHWI score show how each precinct fares compared with the others (Section 3.7). The median is used instead of the geometric mean here because of a high number of input variables (equal to the number of nodes in the precinct), which creates practical issues in product computation (due to the number of digits). Equal weight is assigned to all parameters for the UHWI calculation considering a lack of information or indication in the literature pertaining to prioritization of parameters. This approach can be considered a limitation of this study, given the context of the COVID-19 due to which indicators for measuring the social determinants of health (Badland et al., 2014b) cannot be actively investigated. A detailed analysis of each parameter per precinct (also presented in Section 3.7) is also presented to showcase how each factor contributes to the generation of the UHWI score.

2.3. Application

The method was tested by analyzing and comparing the following four workplace precincts in Sydney, Australia: Darling Square, Parramatta, Olympic Park, and Lidcombe. The analyzed precincts are all located in a dense urban environment and host a large office building belonging to the same business institution, allowing for a fair comparison and benchmarking of the results. The results outlined in the study can be beneficial, alongside other influencing business parameters, for making strategic decisions pertaining to migrating offices to a precinct that can be more beneficial for the health and wellbeing and hence the overall performance of the staff. The developed method is scalable and can be deployed for the calculation of UHWI of work precincts globally.

Fig. 3 shows the location of the four selected precincts. The Darling Square precinct is in the Sydney CBD, with the studied business institution being very close to the Darling Harbor, a popular harbor adjacent to the city center of Sydney. The areas that belong to the CBD are characterized by extremely high density and an intense presence of mixed-use. The Parramatta precinct is divided by the Parramatta River, and it is also a center of major commercial activity. The Olympic Park precinct is located considerably close to the Lidcombe precinct and features mostly parklands and sports and entertainment facilities designed for the Sydney 2000 Olympic games. The Lidcombe precinct is a typical Sydney suburb; although the density is markedly lower compared with the CBD, there exist opportunities for shopping and recreation at the local center. A part of the precinct is also characterized by industrial land use.

3. Results

This section presents the results for each parameter individually before showcasing the UHWI results of all four precincts. The visualizations translate the distance-based analysis to the time needed to reach the closest instance of each parameter (e.g., the closest public transport option) from each node. A set of possible walking times is accordingly defined as 2.5, 5, 10, 15, and 20 min or above. These walking times are translated to distances (200, 400, 800, 1200, and 1600 m or above). The color scheme used in the maps is based on these distances. This process is followed for all nodes per site, and the percentage of nodes that are within each walking time (e.g., 5 min) from the analyzed parameters is also calculated and presented. These

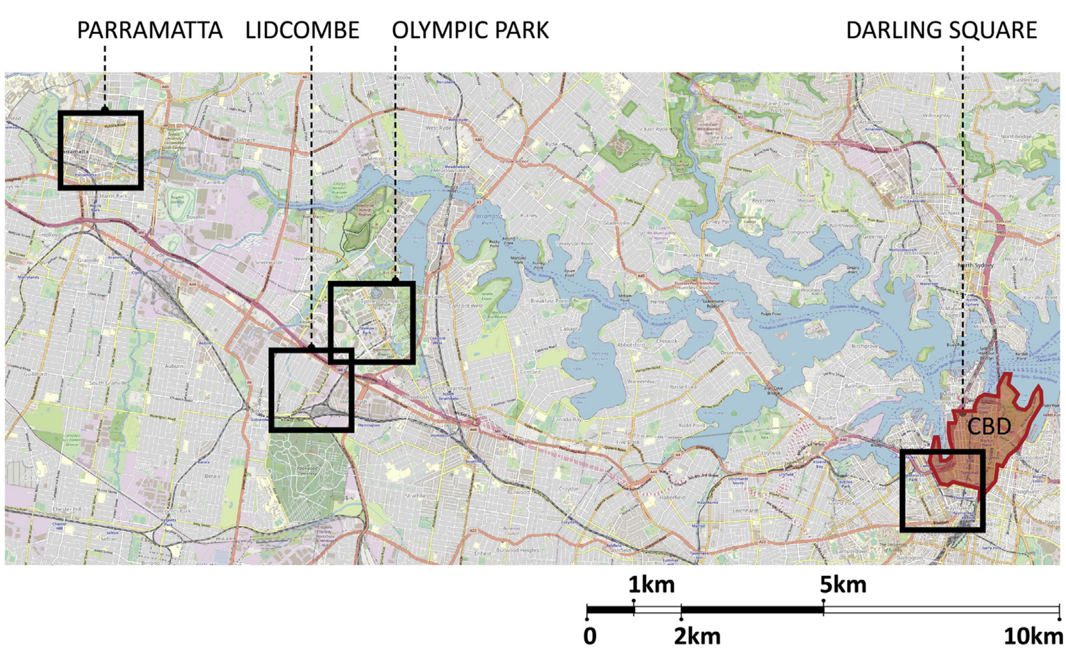

Fig. 3 Precinct locations within Sydney, Australia.

calculations are not a part of the UHWI, but they provide helpful information for each precinct. All the calculations are conducted in Python 3.7 using a custom script.

3.1. Public transport accessibility

The Darling Square and Parramatta precincts are relatively well-serviced in terms of public transport options. The Darling Square precinct has four light rail stops and eight bus stops within 400 m and two train stations within 800 m. The Parramatta precinct has 15 bus stops and 1 train station within 400 m from the center of analysis. The Olympic Park precinct also has one train station and six bus stops within 400 m from the center of analysis. However, the study area in Lidcombe precinct is particularly underserviced in terms of public transport options, as the closest bus stops (apart from one) and train stations are located more than 800 m from the center of analysis.

In addition to the number and type of public transport options in the studied areas, their spatial distribution is also deemed important, as some public transport stops might be concentrated in a small area, leaving other areas underserviced. Fig. 4 shows the distance from each node of the analyzed areas to the closest public transport option. The distribution of public transport services is equitable in the Darling Square and Parramatta precincts, as 60%—65% of the nodes are within 200 m of a public transport option, and 89% are within 400 m. In the Olympic Park precinct, the

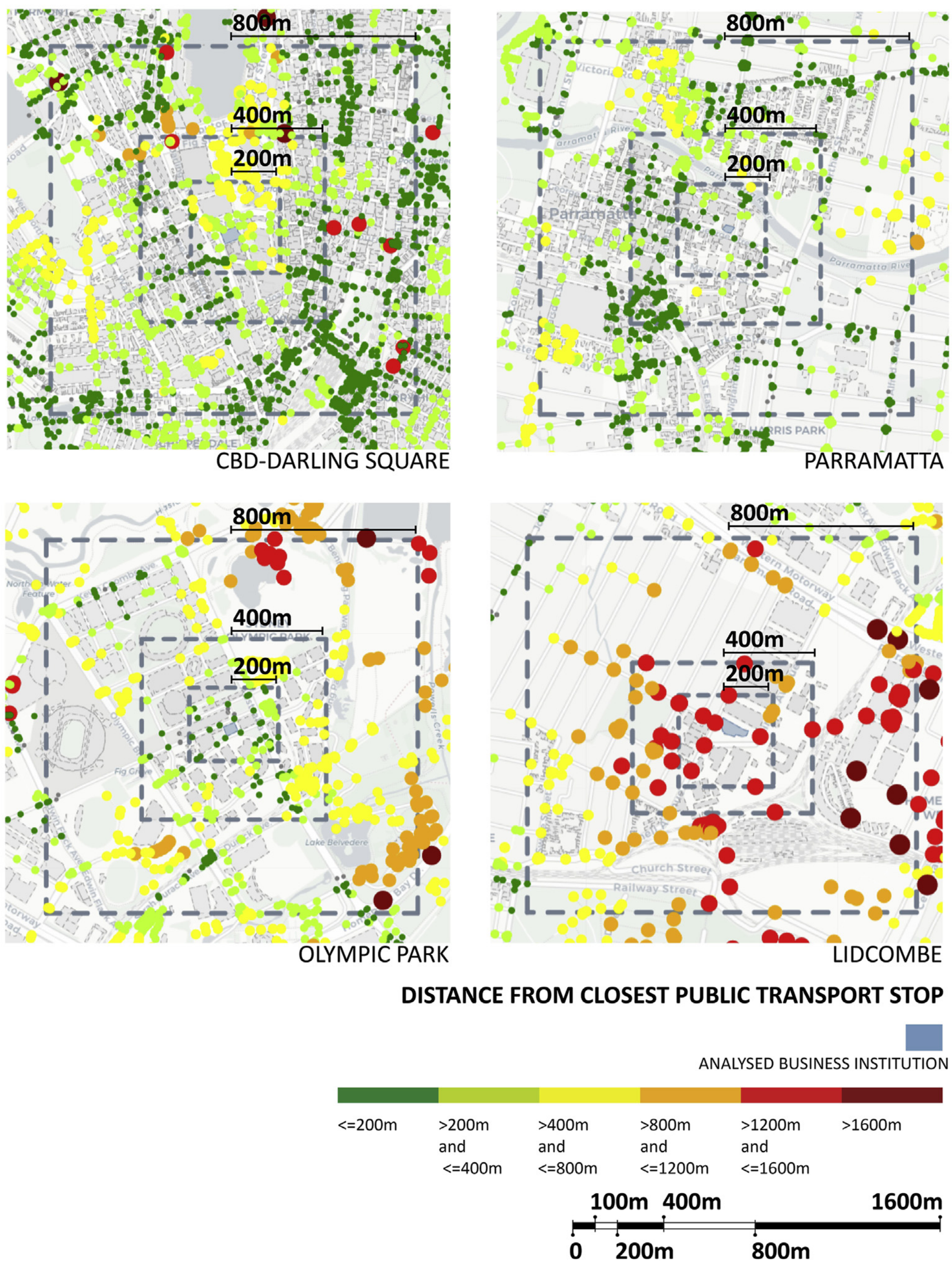

Fig. 4 Distance from each node to the closest public transport stop.

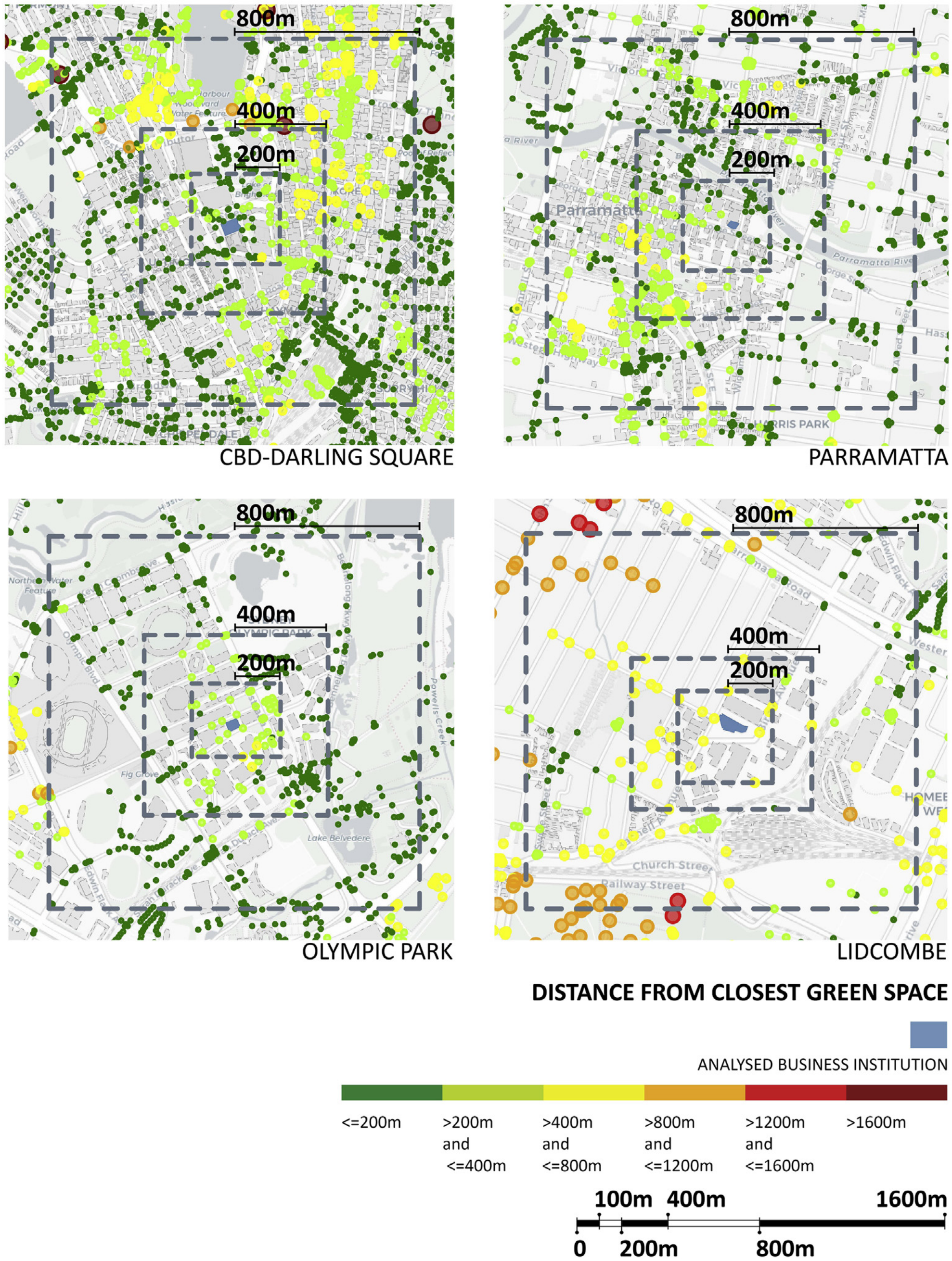

Fig. 5 Distance from each node to the closest green space.

coverage is less sufficient, as considerably fewer nodes are within 400 m (49%), whereas in the Lidcombe precinct, the percentage becomes even smaller (5%).

3.2. Presence of green space

As Fig. 5 shows, all precincts apart from Lidcombe show a favorable distribution of green spaces, with most of their nodes within 200 m or 400 m of a green space. The Olympic Park precinct is the most well-performing, as it has a remarkably strong presence of parklands. Approximately 84% of its nodes are within 200 m of a green space, and 98% are within 400 m.

In the Parramatta and Darling Square precincts, the obtained scores indicate a strong presence of green, as 60% of the nodes are within 200 m of a green space and 89%—95% of the nodes are within 400 m. Furthermore, the Darling Square and Parramatta precincts have green spaces located extremely close to the analyzed workspaces; as shown in the figure, the nodes in the center of the two precincts (the immediate surroundings of the analyzed workspaces) are within 200 m of a green space. The study area in Lidcombe, on the other hand, has fewer green spaces, but 54% of its nodes are within 400 m of a green space, and 88% of its nodes are within 800 m.

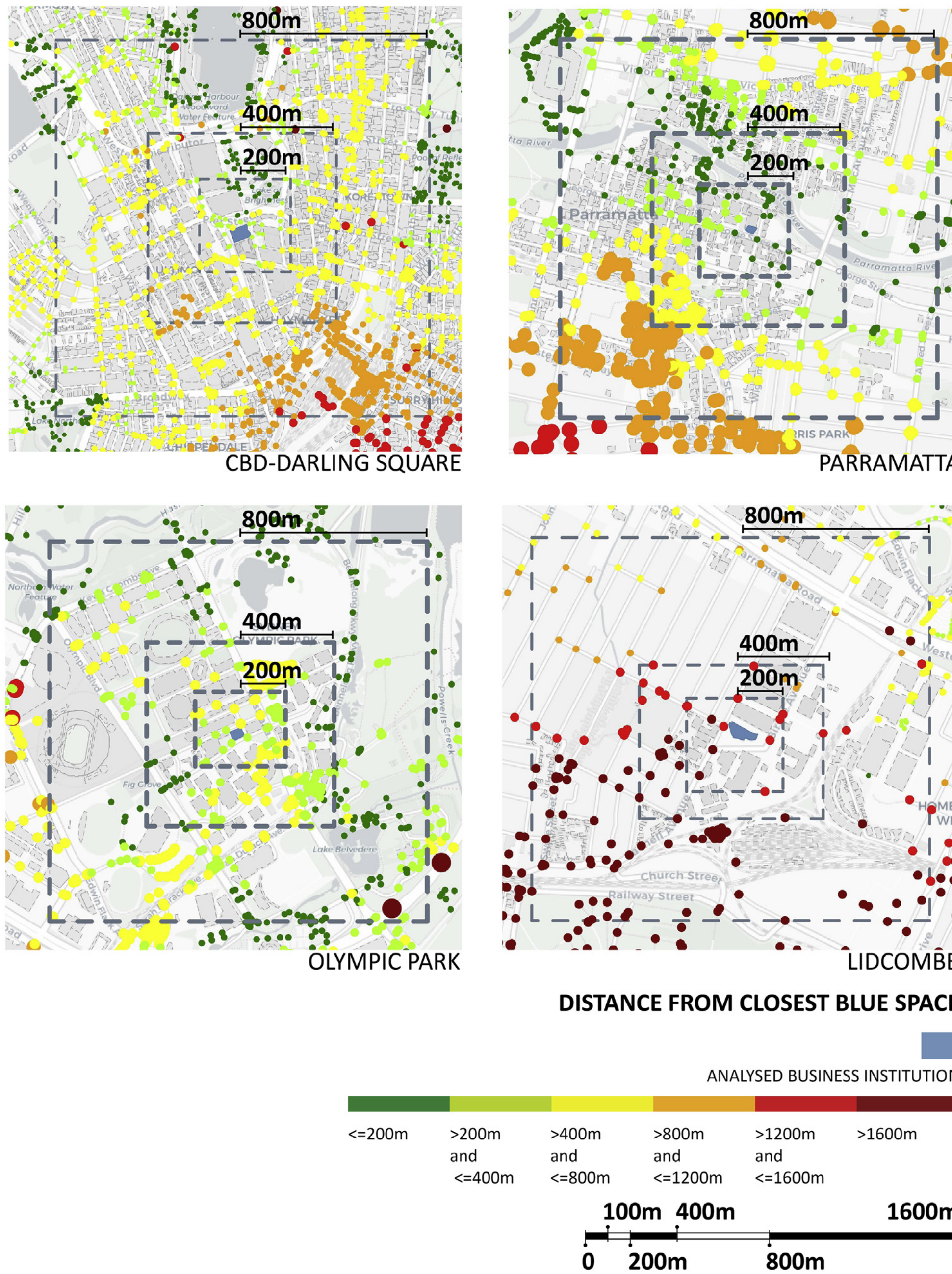

Fig. 6 Distance from each node to the closest blue space.

Analysis is also conducted to calculate the distance from the closest large green space for each precinct. This metric (which is not included in the UHWI calculation) focuses explicitly on large green spaces as these can be used for exercise and recreation. According to the analysis, almost all the analyzed precincts apart from Lidcombe have a strong presence of large and well-distributed green spaces; most of the nodes (75% for Darling Square, 80% for Parramatta, and 96% for the Olympic Park) are within 400 m of a large green space. The Lidcombe precinct, on the other hand, performs poorly in this aspect, as most nodes (72%) have a distance of more than 800 m from the closest large green space.

3.3. Presence of blue space

Although blue spaces are present in the public space in most of the analyzed precincts (because most nodes in all precincts apart from Lidcombe are within 200, 400, or 800 m of a blue space), it is not so strong as the presence of green spaces. The Darling Square precinct is close to the harbor, whereas the Parramatta precinct is close to the riverside, and the Olympic Park has a blue space integrated into its parklands. The Olympic Park displayed the best performance regarding this parameter, as 74% of its nodes are within 400 m of a blue space, and almost all nodes are within 800 m (Fig. 6). The Darling Square and Parramatta

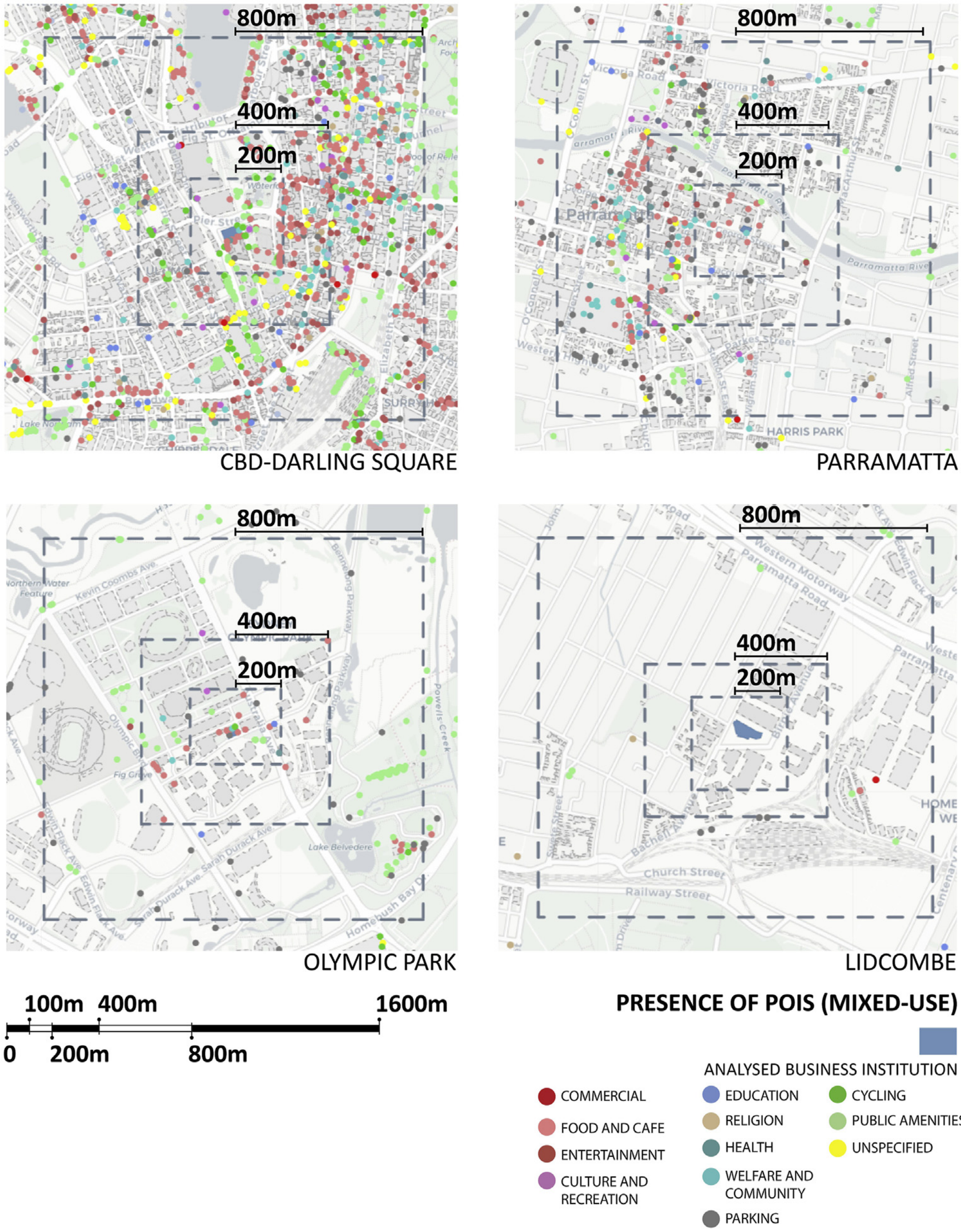

Fig. 7 Presence of mixed-use developments based on POIs.

precincts are less well-performing, as only 30%—40% of their nodes are within 400 m of a blue space, and 73%—76% are within 800 m. However, the areas at the center of the analysis (the immediate surroundings of the analyzed workspaces) are within 400 m of a blue space. The Lidcombe precinct has the lowest scores, as almost half of its nodes are positioned more than 1600 m away from a blue space.

The additional analysis of the distance from large water bodies (which is not included in the UHWI calculation) yields similar results. The Olympic Park has again the highest scores, with most of its nodes (84%) within 800 m from a large water body, and 50% of its nodes within 400 m. The lowest scores are found in the Lidcombe precinct, with more than half of its nodes (66%) positioned 1600 m or more away from a blue space.

3.4. Food environments

The distribution of available food options follows closely the distribution of mixed-use development, as shown in Figs. 7 and 8. The presence of mixed-use is strongest in the Darling Square precinct, followed by Parramatta, based on the identified POIs. There exist considerably fewer POIs in the Olympic Park, and almost none in Lidcombe. Their absence in the Olympic Park precinct can be attributed to the fact that the area is mostly covered by parklands, whereas in the Lidcombe precinct, the surrounding area is highly urbanized.

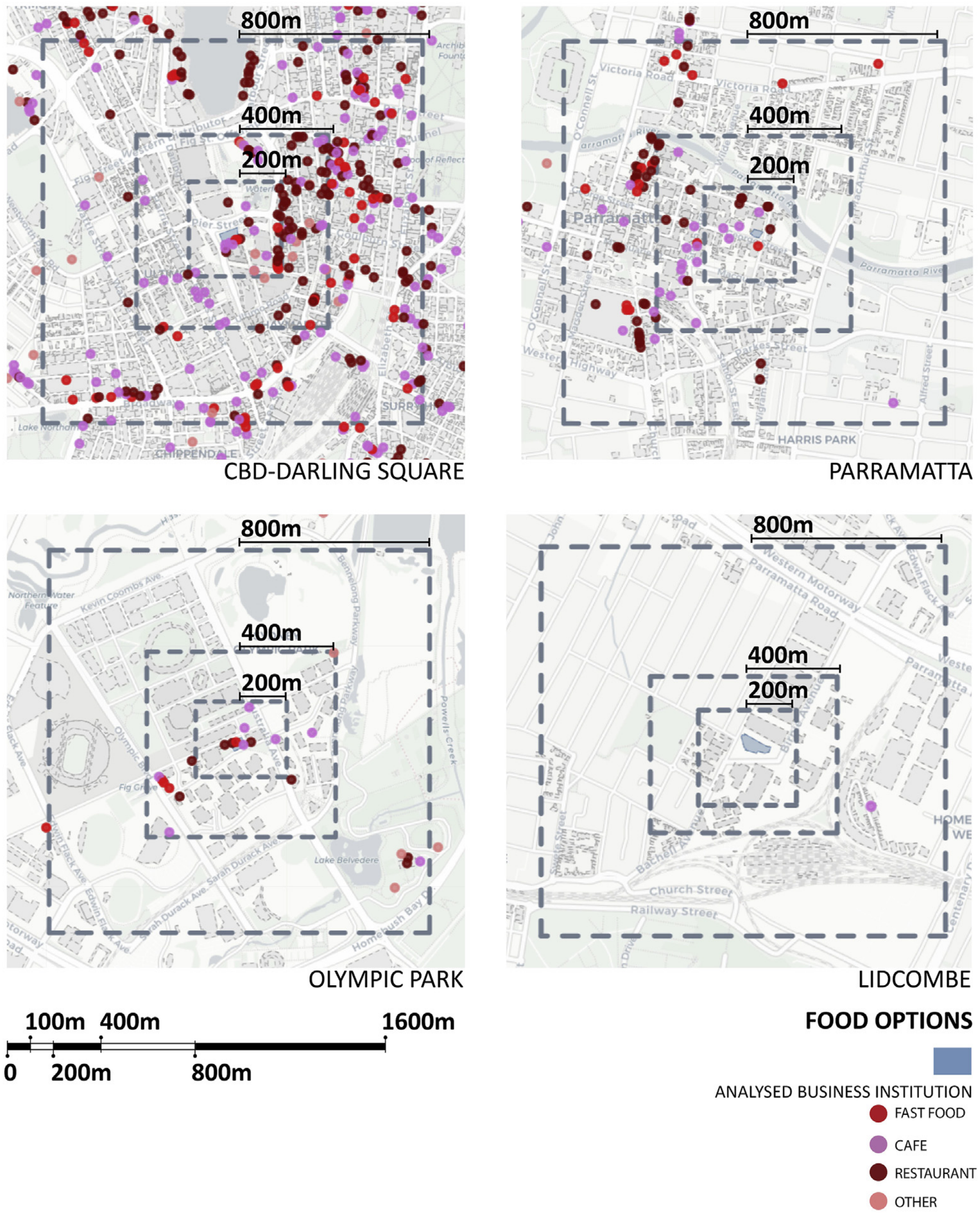

Fig. 8 Presence of food options.

As shown in Fig. 8, in the Darling Square, Parramatta, and Olympic Park precincts, the ratio of fast food to all the available food options is 17%—19% for the area within 800 m from the center. Similar ratios (less than 25%) are also found in the analysis of the area closer to the center (within 200 m and 400 m) for each of the three precincts. In Lidcombe, the analyzed area does not have fast food options; however, this can be attributed to the generally small presence of food options along the site, with only one café within 800 m from the studied institution.

The analysis of the spatial distribution of food environments (Fig. 9) show that there exist an adequate provision of food options within the Darling Square precinct, as 91% of the nodes are within 200 m from any food option (excluding fast food options, as mentioned in Section 2.2.2). The Parramatta precinct is also covered sufficiently regarding this aspect, as 82% of the nodes fall within 400 m of a food option.

The percentage of nodes within 400 m of a food option is lower for the Olympic Park (52%), as most of the nodes that are close to food options are concentrated in the area in the center of the analysis. The Lidcombe precinct has the lowest scores, as 91% of its nodes are 800 m or more from the closest food option. Moreover, an indicative analysis of the menus of most of the identified food environments within 200 m of the center of each precinct showcased the presence of healthy food options, such as salads in the analyzed menus.

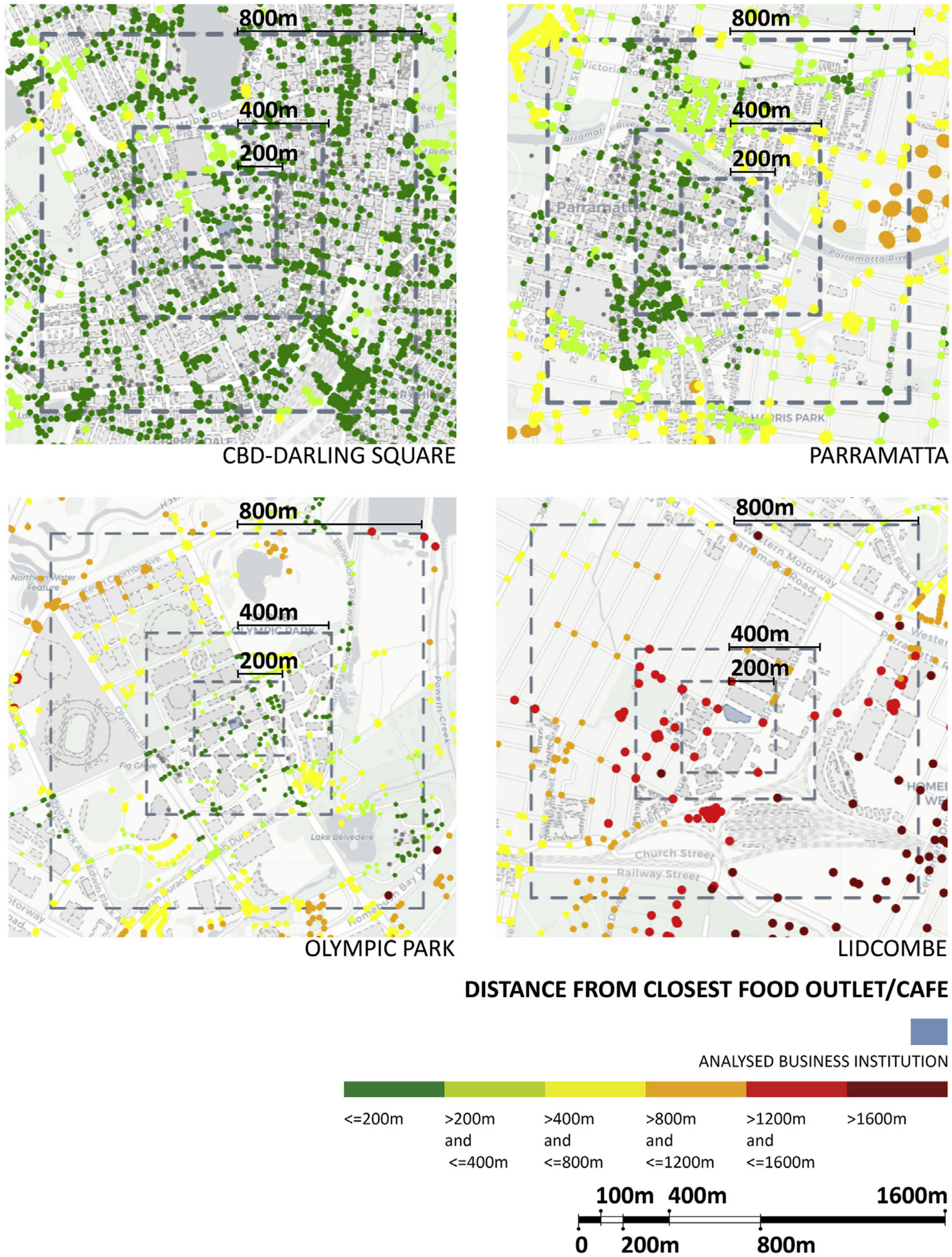

Fig. 9 Distance from each node to the closest food environment.

3.5. Fitness facilities

The analysis of fitness facilities (Fig. 10) shows that the Darling Square and Parramatta precincts are performing adequately concerning the availability of fitness facilities; 51%—53% of their nodes (including those in the immediate surroundings of the center of analysis) are within 400 m from an indoor or outdoor fitness facility, and 93%—98% are within 800 m.

In the Olympic Park precinct, 83% of the nodes lie within 800 m of a fitness facility. Conversely, the average distance from the closest fitness facility is not as high as in the Darling Square and Parramatta precincts. The Olympic Park precinct provides many opportunities for outdoor exercise due to the strong presence of parks. The Lidcombe precinct, with 87% of its nodes located more than 800 m away from a fitness facility combined with an absence of opportunities for outdoor exercise due to a lack of green spaces, scores the lowest.

3.6. Supermarkets and grocery stores

The analysis of the spatial distribution of supermarkets and grocery stores (Fig. 11) shows that the most well-performing precinct in this aspect is the Darling Square precinct. Most of its nodes (71%) are within 400 m of a supermarket or grocery store, and almost all nodes (98%) are within 800 m.

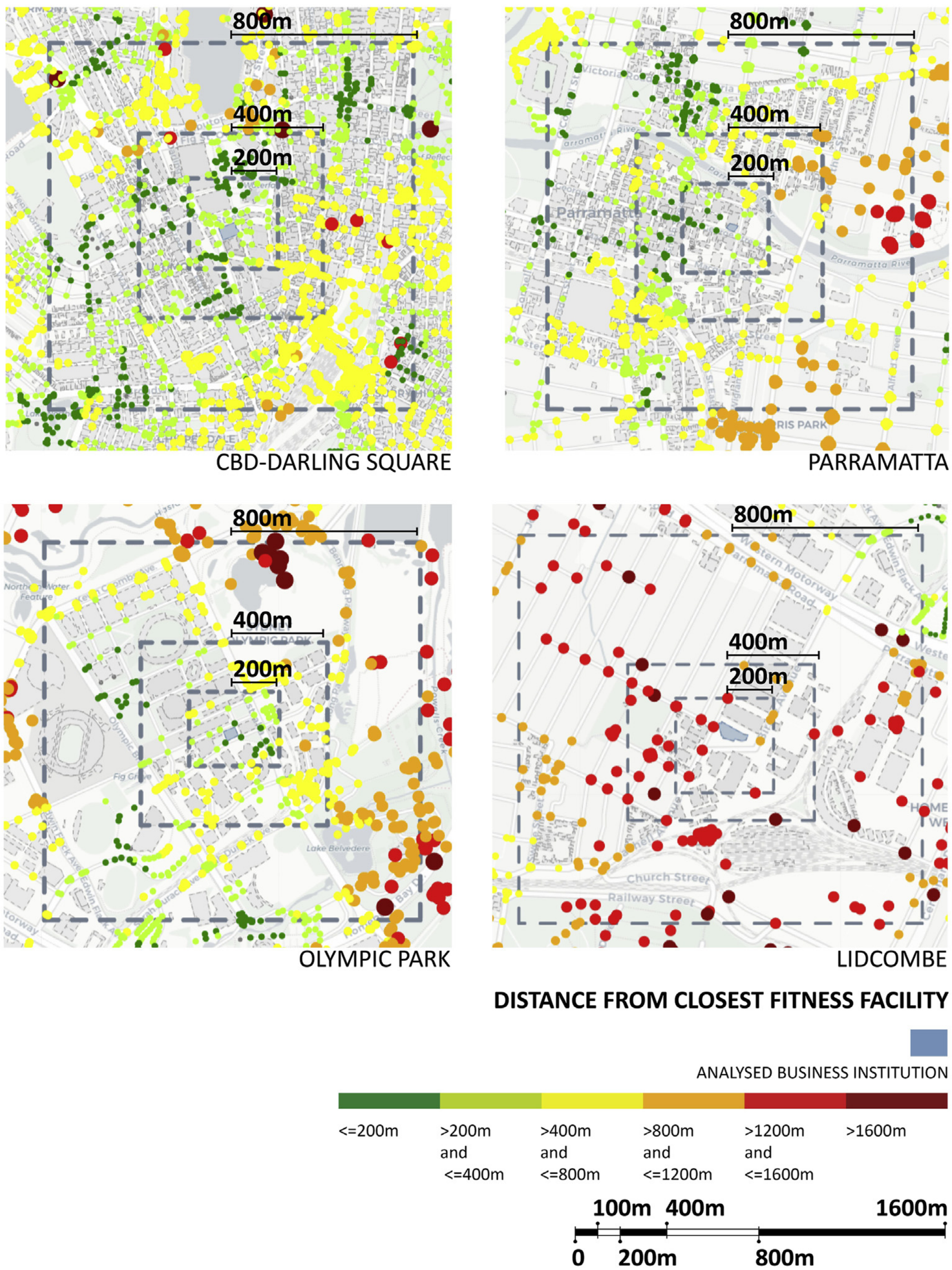

Fig. 10 Presence of fitness facilities.

The Parramatta precinct, with 60% of its nodes within 400 m and 90% within 800 m, ranks second. The coverage is less sufficient in the Olympic Park precinct, where only 45% of the nodes being within 800 m, whereas in Lidcombe, the scores are even lower, as almost half of the nodes (46%) are positioned more than 1600 m from the closest supermarket or grocery store.

3.7. Comparison

Fig. 12 shows the results of the calculation of UHWI based on the formula in Section 2.2.3 for each node. As shown in the figure, the nodes in the Darling Square and Parramatta precincts have scores belonging predominantly to the two highest bands, apart from two areas in the northeast region in Parramatta. The Olympic Park precinct has a cluster of nodes with high scores in the center, whereas the nodes close to the boundary have slightly lower scores. Finally, most of the nodes in the Lidcombe precinct belong to the lower score bands.

After calculating the UHWI for each node per precinct, descriptive statistics were calculated to show its average performance compared with the other precincts. The Darling Square precinct has the highest median UHWI (0.81 ± 0.08), almost equal to that of the Parramatta precinct (median $= 0.80 \pm 0.1$). The Olympic Park precinct

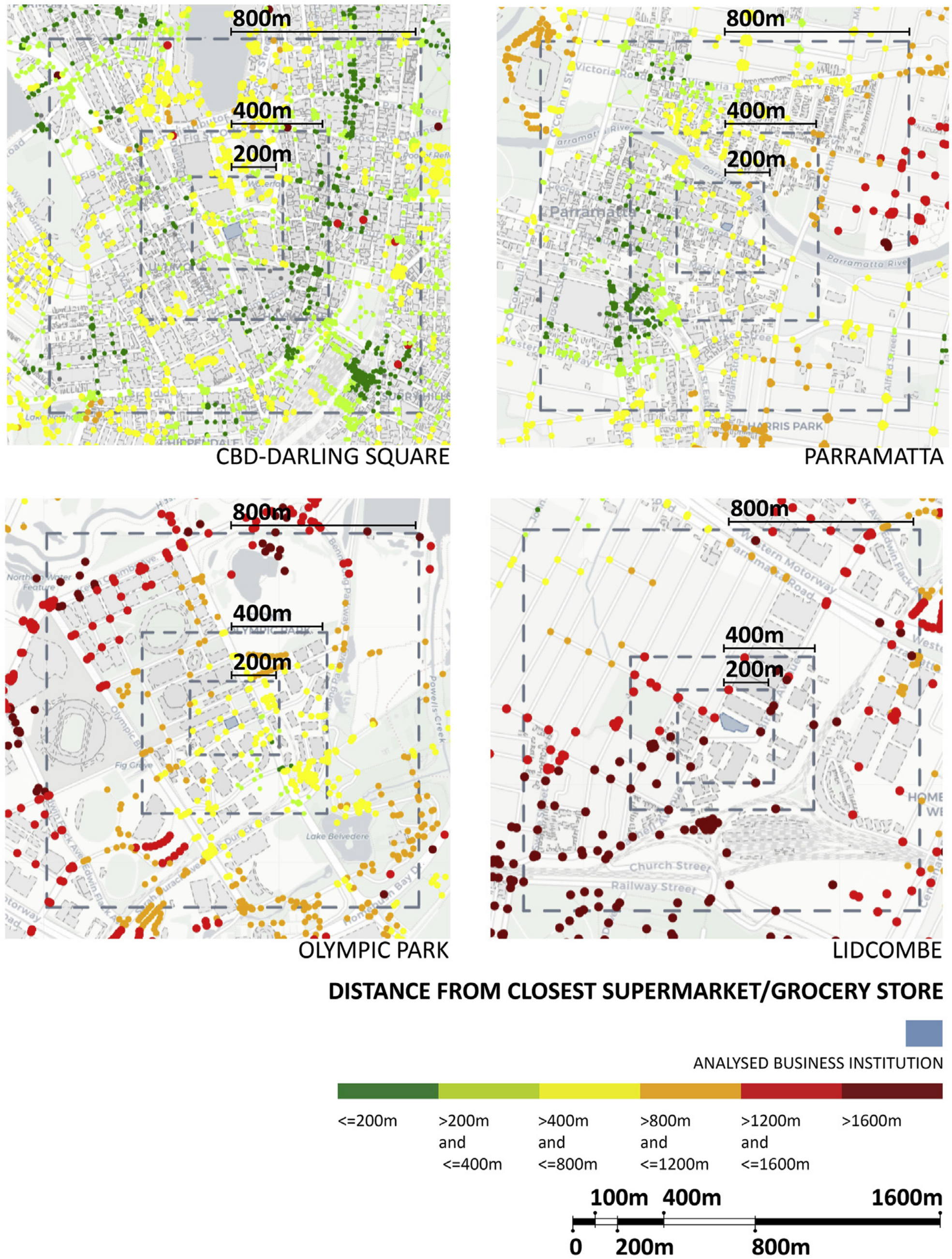

Fig. 11 Distance from each node to the closest supermarket or grocery store.

is the third best (median = 0.72 ± 0.15), whereas the Lidcombe precinct has a considerably lower median score (0.1 ± 0.17) compared with the others.

Fig. 13 presents the median score of each of the factors contributing to the generation of the UHWI. The score was calculated based on the nodes within 800 m of the center in each of the analyzed precincts. This selection corresponds to the nodes presented in the maps shown in Section 3. A high score indicates that the median distance of the examined parameter is low, based on the calculations presented in Section 2.2.3.

As shown in Fig. 5, all precincts have relatively high scores in terms of the distribution of green spaces. The Darling Square and Parramatta precincts perform better than the other precincts in terms of the median distance from food environments, supermarkets and grocery stores, and transport options. The Olympic Park precinct scores higher than the other precincts regarding the distance from the closest green and blue spaces. The Lidcombe precinct has the worst performance than the other precincts in all factors.

4. Discussion

The presented evidence has considerable implications for the analyzed workplace precincts. The Darling Square and the Parramatta precincts have the best performance based

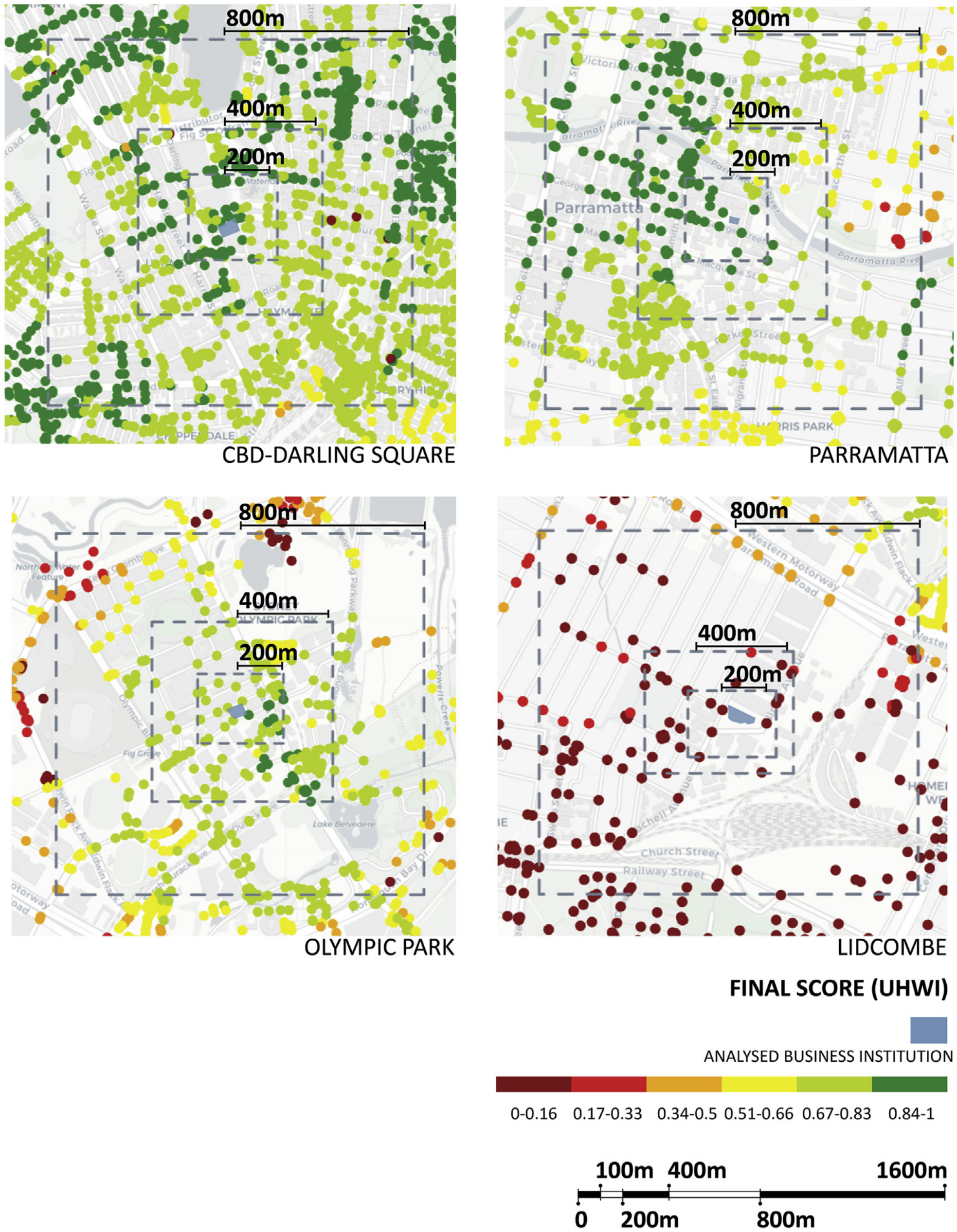

Fig. 12 Node-based spatial distribution of the UHWI for each precinct.

on the UHWI (0.81 $\pm$ 0.08 for the Darling Square, and 0.80 $\pm$ 0.1 for Parramatta) while also sharing a very similar profile. This result suggests that the two locations constitute better options for promoting the health and wellbeing of employees and will thus be preferable locations for offices of the business establishment under study. The two precincts have a particularly high presence of mixed-use, suggesting that they create a more vibrant environment compared with the other precincts. The Olympic Park precinct lacks in terms of vibrancy, but it has a strong presence of natural elements—green and blue spaces. This location will serve workplace environments in need of stress restoration. The Lidcombe precinct underperforms in all aspects, suggesting that employees in this work precinct spend considerable time in an environment that promotes a less healthy lifestyle compared with the other precincts.

The maps showing the spatial distribution of the UHWI are particularly useful for identifying clusters of points that have a low index in terms of urban health and wellbeing. Interventions can then be organized accordingly after analyzing the separate parameters and determining which spatial elements need to be reconfigured. The developed method can also lead to the design of a framework for urban planners and policymakers for the assessment of proposed masterplans during the design of workplace precincts. The connections and interdependence between different parameters need to be considered while interpreting UHWI results and the design of possible

PARAMETER (median value)	PRECINCT			
	DARLING SQUARE	LIDCOMBE	OLYMPIC PARK	PARRAMATTA
Distance from closest blue space	0.64	0.06	0.82	0.67
Distance from closest green space	0.91	0.76	0.98	0.9
Distance from closest fitness facility	0.75	0.25	0.71	0.76
Distance from closest food environment	0.95	0.15	0.75	0.9
Distance from closest supermarket and grocery store	0.82	0.05	0.48	0.78
Distance from closest transport option	0.92	0.42	0.76	0.9
UHWI (median ± STD)	0.81 ± 0.08	0.1 ± 0.17	0.72 ± 0.15	0.80 ± 0.1

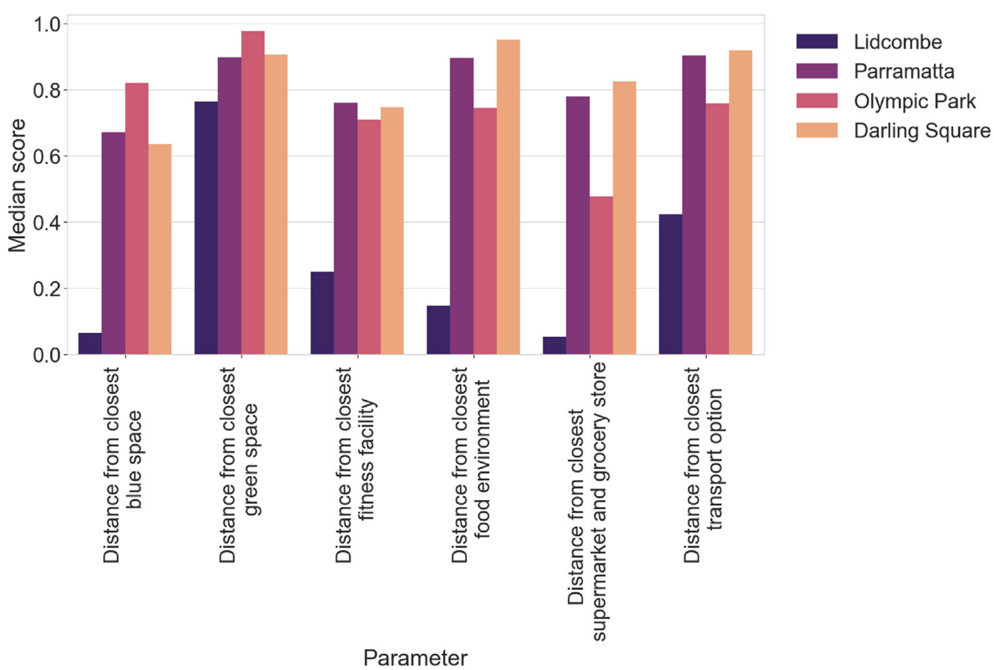

Fig. 13 Presentation of the factors that contribute to the generation of the UHWI.

interventions. For instance, increasing the mix of uses close to the large green and blue spaces in the Olympic Park will be counterproductive, because it will disturb the local ecosystem and reduce the benefits that these spaces have in terms of stress restoration and the promotion of physical activities.

Although the proposed method is easily applicable using freely accessible data—through OSM and without a high computational cost, the study has the following limitations that need to be considered. The quality of the analysis is based on the accuracy of the tags in the OSM data. A quality check is thus conducted for the four analyzed precincts to cross-check the accuracy of the tagged data. The check reveals that the acquired information is considerably close to the actual situation for most of the examined parameters. Only a few public transport stops are missing from the Lidcombe and Olympic Park precincts. The geocoordinates marking some parks or blue spaces, which are missing from the acquired OSM data, should also be filled manually. Some large green spaces are also broken down into smaller spaces in the acquired data; the analysis of large green spaces is required, thereby overwriting these data points with the correct ones. Furthermore, the study does not include a separate measurement of two parameters that are significant in the context of health and wellbeing, namely, walkability index and the presence of mixed-use. The exclusion of the walkability index is decided because the analysis already covers the proximity to amenities related to it (e.g., public transport stops and supermarkets). The separate measurement of mixed-use is included because its spatial distribution is highly similar to the spatial distribution of the *distance to the closest food environment* parameter (see Figs. 7 and 8).

The developed UHWI's uniqueness is in the combination of multiple parameters that affect urban health and wellbeing in a single metric. The separate analysis of each parameter is equally invaluable, as it details underperforming areas per precinct. However, one should also consider that the influence exerted by the chosen urban parameters in the calculation of the final score may differ in other contexts based on the nature of tasks performed by the employees, as well as the overall business aim of the institution.

Although this study focuses on the spatial analysis of workplace precincts, the proposed method can also be used to assess spatial determinants of health and wellbeing for other tenants of interest, such as schools or universities. The analysis can then be modified accordingly by prioritizing parameters that are more significant for that context or enriched with new factors, such as the assessment of traffic levels around educational facilities to avoid accidents.

5. Conclusions

This study outlines a method for the assessment of physical determinants of health and wellbeing for workplace precincts using a spatial analysis approach and the subsequent development of an UHWI. The method is used to analyze and compare the performance of four workplace precincts with offices belonging to the same business institution per precinct in Sydney, Australia. The analysis shows considerable differences between the four precincts while showcasing the strength of the proposed method and its potential use by business leaders and precinct planners alike as an evidence-based tool that compares potential future work precinct locations and assists in making an informed decision regarding the most well-performing precinct regarding urban health and wellbeing parameters. The method also has the potential to be further developed as a tool that creates a profile for different work precincts of an organization and assists in deciding which location might be more suitable for its employees.

The analysis focuses on parameters that are measurable using spatial analysis tools and freely available open data. Although these spatial parameters are vital (as established in Section 2.1) for understanding differences in the spatial distribution of factors that are among the most significant in urban health and wellbeing research, other design elements are also important; particularly those found at the small scale, such as the presence of shading elements and benches. A qualitative assessment of selected areas within the studied precincts is thus recommended to obtain an in-depth understanding of the site and validate the results of the quantitative analysis. A qualitative analysis has been conducted for this purpose for the focus area (200 m radius) in the Darling Square precinct and will be presented in a future study.

Declaration of competing interest

Authors have no competing financial, professional, or personal interests from other parties.

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