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Promoting Urban Corridors in Saudi City Center to Enhance Walkability Using Multi-Criteria Decision-Analysis Methods

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Abstract: Saudi Arabian cities have rapidly expanded their urban areas, especially their city centers, over the last four decades. This growth has led to increased vehicular usage. As a result, the daily walking experience for residents has been adversely affected. Walkability has several positive effects on people's health and the urban environment. It serves as a means of transportation and helps create a sense of place. This enhances the legibility of urban structures and deepens emotional bonds with the city. This study uses the medium-sized Saudi Arabian city of Onaizah as a case study. It explores the feasibility of creating urban walking corridors to encourage more walking. According to Saudi Arabia's Vision 2030, sustainable urban development and improved quality of life are key priorities. The study addresses walkability as a way to enhance the urban landscape of the city center. Geographic Information Systems (GISs) were used to analyze data and generate urban corridors in the city center. The results indicate that walking in Onaizah can be improved through three urban corridors. These corridors measure 1335 m, 1624 m, and 1937 m, respectively. They represent urban, commercial, and heritage corridors. This provides planners and decision makers an opportunity to prioritize pedestrian connectivity and improve the physical environment. Such efforts contribute to sustainable urban development. Various criteria-analysis methods were employed to assess the factors that led to the conclusion of these urban corridors. This includes evaluations of land use, transportation, and environmental considerations. The study aligns with Saudi Arabia's Vision 2030 by promoting walking and enhancing overall walkability. It also aims to create a sustainable and livable urban environment for the community in Onaizah.

Keywords: urban corridors; walkability; urban planning; city; sustainability; GIS

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1. Introduction

The rapid population growth and urbanization in Saudi Arabian cities have led to significant changes in their forms. This situation calls for the creation of sustainable and walkable urban environments. Increased urbanization rates have caused cities to expand, leading to new challenges related to ease of movement. These challenges are important for achieving a better quality of life, as emphasized by Saudi Arabia's Vision 2030 [1,2]. In response, there is growing interest in examining the walkability of urban areas. This focus

includes attractive sites and street networks and their impact on pedestrian movement and accessibility. Finding sustainable transportation solutions in densely populated urban areas is critical and must be addressed. Highlighting walkability as a key urban design element can provide benefits in three crucial areas: health, livability, and sustainability [3,4]. Research advocates that the long-term health benefits of walking and physical activity should incentivize the redesigning of cities to be more walkable. This redesign can significantly reduce car dependency and develop sustainable transportation systems for growing urban populations. Several physical aspects of the built environment must be analyzed to facilitate and encourage walkability. These include connectivity, accessibility, proximity to destinations, greenspaces, commercial areas, and proximity to transit [5,6].

In broad terms, walkability refers to how conducive an urban environment is to walking and wandering activities. It must include several key attributes. These include the design and layout of streets, the presence of sidewalks and pedestrian crossings, and the availability of amenities and services within walking distance. Overall safety and comfort for pedestrians are also essential [5,6]. Walkable urban areas promote healthy lifestyles and physical activity for residents. They foster social interactions, which reduces dependence on cars and positively impacts the environment. To achieve walkability, urban environments must be suitable for walking and provide hiking opportunities. This includes effective street design, designated walking paths, and proximity to amenities. Public safety and comfort for pedestrians are also crucial [7,8].

The idea of walkability and its relationship with metropolitan planning and design has garnered significant attention in recent years. This is no surprise, as walkability emerges as a pivotal urban design element with the power to unlock benefits across three crucial domains: health, sustainability, and livability. At the heart of this report is the unparalleled impact of walkable communities on public health. The article persuasively argues that the long-term physical and mental health advantages associated with walking and active lifestyles should be the primary impetus in driving efforts to redesign cities to be more walkable [9]. By reducing reliance on private vehicles, walkable neighborhoods can foster healthier, more physically active populations. Yet, the benefits of walkability extend far beyond individual wellbeing. Walkable urban design also serves as a linchpin for sustainable development. By facilitating decreased automobile usage and emissions, walkable cities can make substantial strides toward environmental sustainability goals [10]. The review highlights the crucial physical elements of the built environment, such as connectivity, accessibility, and proximity to destinations, that enable and encourage walking as a primary mode of transportation [11,12].

Moreover, walkable communities deliver enhanced livability for urban residents. Factors like the presence of green spaces, commercial areas, and transit hubs contribute to the overall quality of life and sense of community in walkable neighborhoods. This, in turn, can attract and retain residents, further strengthening the social and economic vitality of the city. Recognizing the multifaceted, symbiotic relationships between walkability, health, sustainability, and livability, this review underscores the urgent need for policymakers and developers to prioritize walkable urban design [13,14]. By leveraging various evaluation frameworks and indices, cities can optimize the key elements that foster walkable, healthy, sustainable, and livable communities—a crucial step in addressing the challenges of urban population growth and development.

Furthermore, the use of Geographic Information System (GIS) techniques can achieve the objectives of this study to enhance walkability in Saudi cities and improve urban sustainability through processing the data; these data represent the elements that illustrate the walkability of the city of Onaizah, as well as the street network of the city center, the various uses of land, facilities, and social and demographic impacts. Such approaches can aid in conducting multi-criteria decision-making analyses, supporting suggestions for optimal walking corridors associated with urban, commercial and heritage destinations in the city [15].

Saudi Vision 2030, which represents a long-term economic and social reform vision for the humanization of Saudi cities, was announced by the government of the Kingdom

of Saudi Arabia in 2016; it gives great attention to developing infrastructure, including transportation, housing, and logistics services, and focuses on demonstrating the human character of cities in Saudi Arabia and reflects an interest in healthcare [15]. There is also a focus on exploring the extent to which walking can be achieved in a way that reduces the use of cars, which are a major cause of air pollution and greenhouse gas emissions. Walkable cities are also more socially and economically vibrant, because they encourage connectedness between people and support the development of local businesses. Using Geographic Information Systems to create walking corridors leads to the creation of more sustainable and vibrant cities that are more capable of meeting the needs of their residents in a way that is compatible with urban cities that are characterized by rapid urbanization. On the other hand, we find a relationship between spatial formations and human behavior within urban environments. This relationship is achieved by studying the connectivity and integration between street networks, buildings, public, and recreational and heritage spaces; the study of this assists in understanding how pedestrian movement, social interactions, and perception of space are shaped [16].

In addition, Geographic Information Systems (GISs) help in evaluating walkability factors using spatial data analysis techniques [17,18]. GISs integrate different data layers, including street networks, land use, facilities, and social and demographic information, also allowing for a comprehensive assessment of walkability, producing maps, and analyzing various aspects of the urban environment. This supports evidence-based decision making in the urban planning process, providing meaningful outcomes for improving walkability [19]. In studying walkability in cities, there is no doubt that urban planning affects the movement and behavior of people within them, which helps city decision makers and planners to determine the most appropriate routes to take [11,20,21].

Previous studies have been published that have conducted evaluations on the accessibility of streets, e.g., Lamíqui used a method to examine the accessibility of the road network and investigate how the layout of the urban road network can affect pedestrian flow [22]. Their method captures movement patterns as they are influenced by the topology of a road network. Recent studies have incorporated Geographic Information Systems to provide ease and additional data support. Numerous studies have determined street network accessibility by using the GIS and analyzing it at different scales inside the city [23,24]. For example, researchers have conducted correlation analyses to capture pedestrian traffic and predict the future state of cities like Athens and compare it to the current state [25]. They used a regression analysis model to evaluate the effect of environmental characteristics, such as land use and terrain, on pedestrian density and walking ease. The study was also conducted in selected locations on the university campus [20]. Moreover, studies have examined the relationship between graphical measurements of street networks and observed movement patterns in cities such as Copenhagen [17]. These studies emphasize the importance of understanding pedestrian movement and the impact of street networks on walkability in urban environments.

By promoting walkability, cities can create more active and engaging public spaces that foster a sense of community and support the growth of local businesses. The development of urban corridors and walkways is a key component of enhancing walkability in cities. Researchers have shown that well-designed and well-maintained urban corridors can increase the number of people who walk, making it easier and safer for residents to move around on foot [26,27].

Given that the goal is for urban residents to be able to meet their basic daily needs within a 15 min walk or bicycle ride from their homes, such as accessing essential services, employment, and amenities, within a 15 min walk or bicycle ride from their homes. Accordingly, the “15 min city” and “10–15 min Walk” concepts encourage the development of compact, walkable neighborhoods that are well-connected and support a range of different activities. This can have a number of benefits for both the environment and the community, including increased physical activity, improved air and water quality, and enhanced social and economic opportunities [26,27].

Finally, a study by Suleiman, Sani et al. [28] to locate an optimum, economic short urban corridor that connects two towns in Kano state of Nigeria (Gaya and Hamdullahi). The process of selecting an optimum route is highly complicated due to the many variables that must be taken into consideration for achieving the best results.

Existing studies on the sustainable development of human and natural resources lack effective guidance for decision makers. To address this critical issue, our research takes a pioneering approach that integrates various urban elements. This study investigated the possibility of generating walking corridors to increase the walking habits of residents in the central district in Onaizah city, as a model of medium Saudi Arabian cities. This study explores the possibility of providing historical, health, and social–commercial walking urban corridors for enhancing the walkability of a city. Historical walking corridors can be an important tool for preserving a city's cultural heritage and providing visitors with an opportunity to learn about its history. Health walking urban corridors, such as those that link parks and other green spaces, can be an important tool for promoting physical activity and improving public health. Social–commercial walking urban corridors, such as those that connect different neighborhoods or communities and amenities, can help to foster a sense of belonging and promote social interaction and help to sustain the commercial and economic activities.

Moreover, in order to help cities and resilient landscapes achieve their goals of economic development while also benefiting society and the environment, more research is arguing for the increased use of nature-based solutions (NBSs); the literature recognizes NBSs as some of the most complete strategies for creating resilient cities and landscapes. Governments and scientific communities now have to overcome the challenge of translating generic statements into useful implementations.

Seven primary NBS actions are suggested for implementation based on these goals: (1) establish NBSs for coastal resilience; (2) utilize NBSs for urban regeneration; (3) implement multifunctional nature-based watershed management and ecosystem restoration; (4) utilize NBSs for urban regeneration; (5) utilize NBSs to increase the sustainable use of matter and energy; (6) use NBSs to increase ecosystems' insurance value; and (7) use NBSs to increase the retention of carbon [29,30].

Through the above actions, the present study uses Geographic Information System (GIS) techniques and the Analytical Hierarchy Process (AHP), a structured decision-making framework that provides a systematic approach to evaluate multiple criteria that influence walkability. Additionally, the study focuses on the integration of the cultural and historical context to improve the pedestrian experience and create a vibrant urban environment around heritage sites, green areas, commercial sites, and mosques.

Within the context of the abovementioned urban paradigms and development methodologies, the present research discusses the following questions:

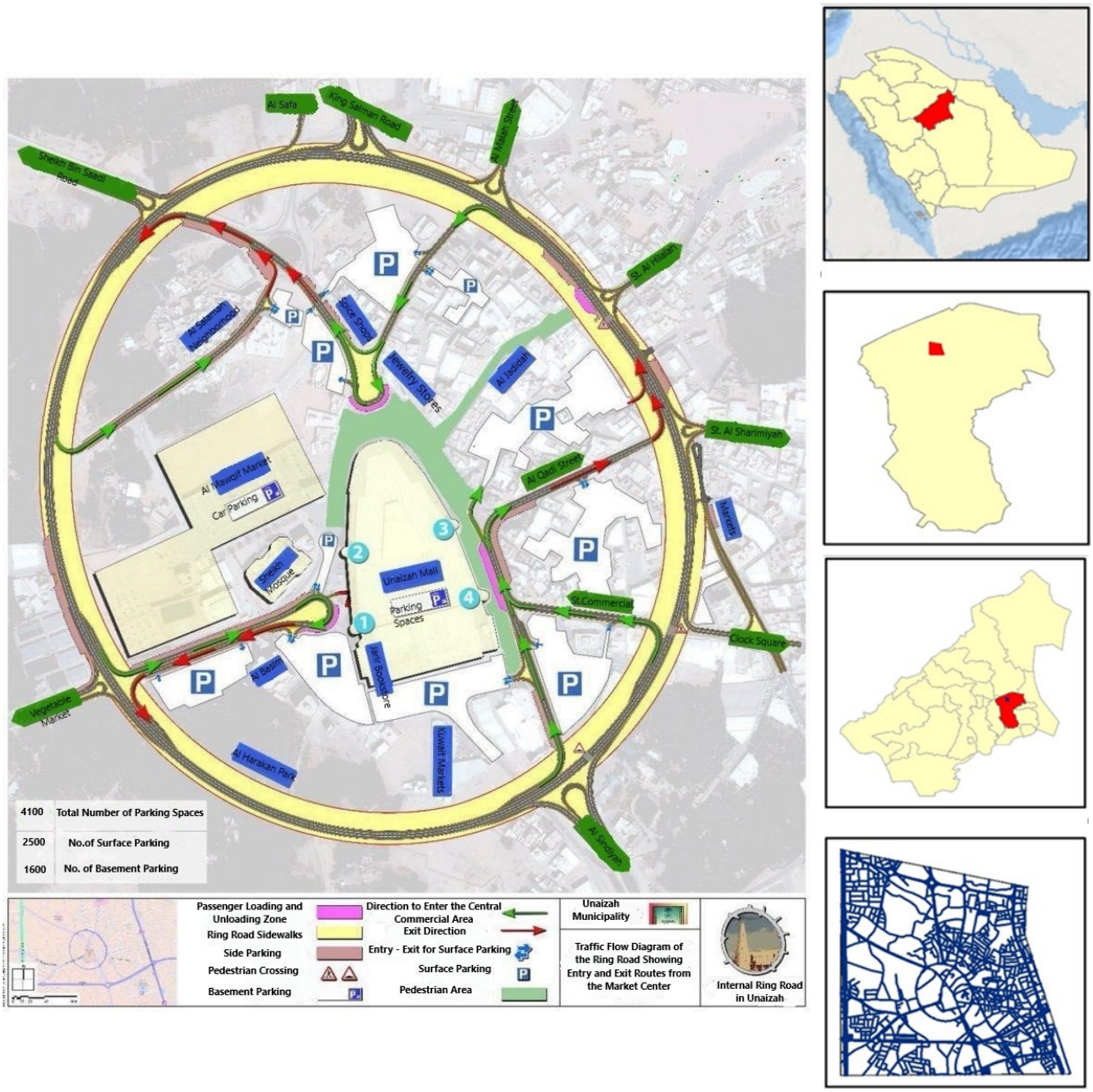
- In what ways has the walkability and everyday walking experience of Saudi Arabian citizens been affected by the country's city centers' explosive urban growth over the last forty years?
- How can improved walkability in the plans of Saudi Arabian municipalities benefit the environment and the wellbeing of its citizens?
- In the medium-sized Saudi city of Onaizah, how can the creation of urban corridors promote increased walking among residents and users?
- What GIS-based analysis methods can be used to identify and assess the feasibility of implementing three walking corridors with mixed-use functions (urban, commercial, and heritage) in the city center of Onaizah?

2. Study Area

2.1. Physical Environment

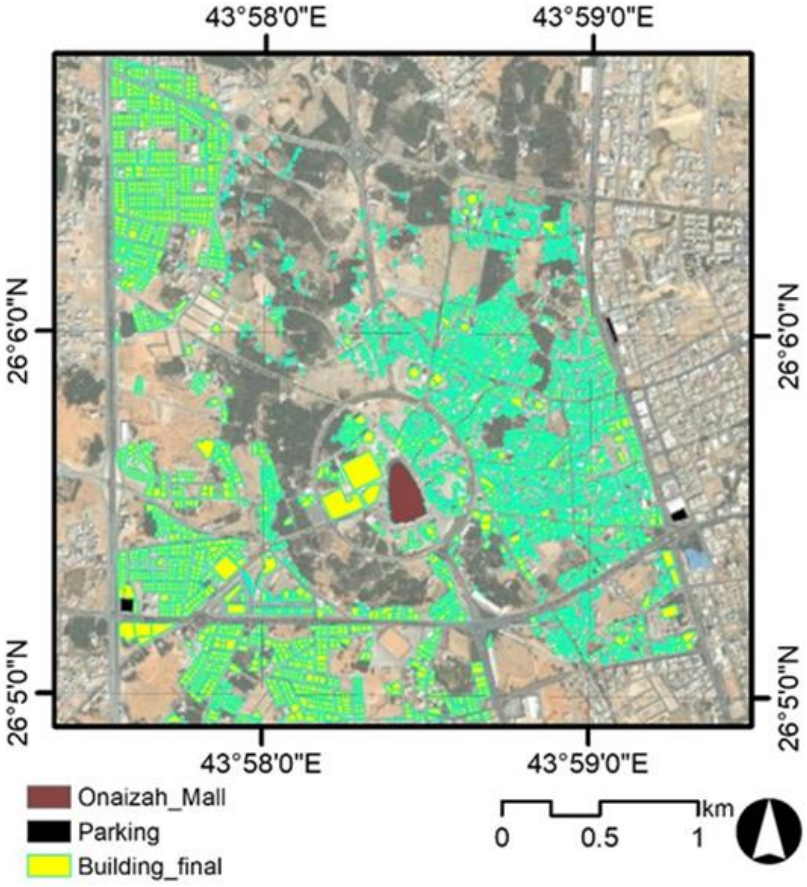
Onaizah City is located in the Al-Qassim Central Region of Saudi Arabia, about 320 km northwest of the capital, Riyadh. It is one of the major urban centers in the Qassim Province, serving as an important economic, cultural, and administrative hub. Onaizah is a candidate

for integration with the nearby city of Buraydah as a National Growth Center, playing a pivotal role in the National Physical Strategy. The term National Growth Center refers to urban areas designated by Saudi Arabia's national planning strategy to serve as key hubs for economic, administrative, and cultural development. The National Physical Strategy is a framework developed by the Ministry of Municipal and Rural Affairs (MOMRA) to guide urban growth, infrastructure development, and sustainability efforts across the Kingdom. Onaizah is located at the southern gate of the Al-Qassim region, connecting with Riyadh, Al Madinah Al Munawwarah, and Ha'il. As the main urban center in the province, it provides a variety of government and regional services to its residents and the surrounding areas. Onaizah is part of the arid zone in central Saudi Arabia (Figure 1a).



(**a**)

Figure 1. *Cont.*



(**b**)

Figure 1. Location and pedestrian infrastructure plans of the city center in Onaizah. [Source: The Authors after Onaizah Municipality development project, MOMRA, KSA]. (**a**) Onaizah pedestrian infrastructure project for the urban core (1439–2018); proposed by the National Physical Planning Strategy; this detailed plan highlights the pedestrian network integrated with the internal ring road. The project aims to enhance walkability within Onaizah's urban core, improving connectivity and accessibility. [Source: Onaizah Municipality, MOMRA, KSA] [31]. (**b**) Location of extended study area: Onaizah City Center.

2.2. Climatic Environment

According to the Köppen climate classification, Onaizah experiences a hot desert climate (BWh), characterized by a relatively mild winter and an extremely hot and dry summer. The region's climate is known for its intensity, posing challenges to human activity and comfort. In this climate, maintaining suitable pedestrian temperatures during both summer and winter is difficult. This challenge necessitates the planning of pedestrian infrastructure that encourages walking by outfitting urban corridors with pedestrian-friendly environments. To create a suitable urban environment, it is important to consider the prevailing climatic conditions. This research focuses on the climatic environment as a constant, with measurable variables treated as factors for evaluating urban corridors. GIS methods are employed to obtain standard urban corridor results within appropriate walking distances of 10 to 15 min, using a time-based walkability approach (TBW) [32,33].

Onaizah has experienced significant urban growth and development; Onaizah municipality suggested the city urban core development project (Figure 1), presenting an appropriate pedestrian infrastructure plan. This includes the following aspects [31]:

- Ground-level parking lots (2500 cars);
- Underground parking lots (1600 cars);

- Pedestrian plazas and on-street furniture;
- Loading/unloading docks for existing commercial facilities;
- Internal ring road pdestrian sidewalks;
- Three pedestrian culverts for internal ring road crossings to car-parking areas;
- Urban gates for market accessibility (in/out)

This development has significantly transformed Onaizah's urban fabric and transportation infrastructure, making it an ideal site for exploring walkability features. The city center of Onaizah serves as the central business district (CBD) and is the focal area for commercial and social activities. Located in the heart of Onaizah, the city center features a variety of retail shops, restaurants, offices, and traditional markets (such as the Gold Souk and Al Gudaida Traditional Souk), along with public amenities.

The city center offers a diverse range of retail establishments, from local businesses to larger national and international chains. It is a bustling area where both residents and visitors come to shop, dine, and socialize. Uniquely, the district blends the modern with the historical. Lush palm farms, which also serve as parks and restaurants, coexist alongside heritage palaces and historical sites. This creates a vibrant environment where residents can enjoy a meal under the palm trees or explore the rich cultural heritage surrounding them.

3. Materials and Methods

3.1. Data

Walkability in cities is usually affected by many factors, such as accessibility to essential services [18,34], the variety of land uses [27,35,36], residential density [37], connectivity of the street network [19,20], pedestrian-friendly street design [17,22,36,38], and safety from traffic and crime [19,39].

In this study, as it explores the possibility of generating thematic walking corridors, seven variables—heritage sites, green areas, commercial sites, mosques, street slopes, activities, and vacant parcels—impact the street network as an incubator for pedestrian walkways, as shown in (Figure 2). Other variables, such as lighting, pedestrian safety, and other relevant factors, were excluded because all streets are well-lit, all streets in the study area have two lanes with a sidewalk on both sides, and there is no crime recorded in the area.

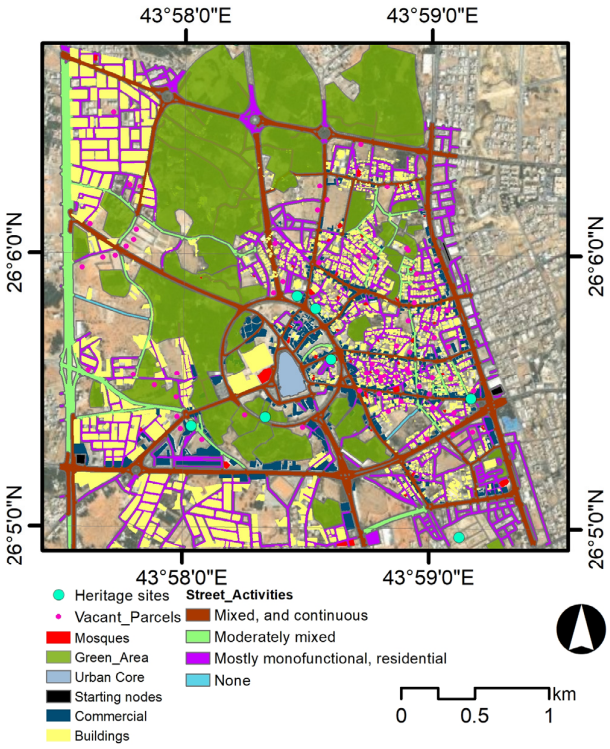


Figure 2. A multi-layered perspective used for walkability analysis. [Source: the authors].

The street network was obtained from Open Street Maps. Commercial sites, buildings, and mosques were obtained from Onaizah Municipality. The green area, palm farms, and vacant parcels were obtained by digitization of the satellite images. The heritage sites and activity levels were obtained from a field visit to the study area.

The street slope was generated based on the digital elevation model (DEM), which is a representation of the bare ground (bare earth) topographic surface of the Earth, excluding trees, buildings, and any other surface objects. The Shuttle Radar Topography Mission (SRTM) digital elevation model (DEM) is free and publicly available [40]. The SRTM project is a joint endeavor of the National Aeronautics and Space Administration (NASA), the National Geospatial Intelligence Agency, and the German and Italian Space Agencies, and it was launched in February 2000. The SRTM uses dual radar antennas to acquire interferometric radar data, which are processed to obtain digital topographic data; the corresponding dataset includes the most complete, high-resolution DEM data for the Earth [41].

3.2. Least-Cost Path (LCP) Analysis

Least-cost path (LCP) analysis is a technique used in Geographic Information Systems (GISs) to determine the optimal or least-cost path between two locations based on a specified cost surface. It is widely applied in various fields, such as transportation planning, urban planning, natural resource management, and environmental modeling. LCP was applied in this study to generate the shortest urban corridors that maintain the 10–15 min walking concept.

The raster cost surface assigns different cost values to different locations in space. It is formed by combining raster landscape of the proximity to the four main investigated variables in a weighted manner. Generally, the values of each landscape are scaled to the same range for weighting [42]. In the case of raster space, two grid cells sharing one grid edge or one and only one grid vertex is assumed to be (orthogonally or diagonally, respectively) adjacent to each other; a path is represented by a sequence of adjacent cells or of arcs implied by adjacent cells. If, as is often the case with raster-based GIS, the distance between two adjacent cells is calculated as the straight-line distance between their centers multiplied by their mean value, the following formula gives the length of a path, P, on a surface, f, which is here referred to as path P's 'sum-f length' and denoted by L_{sum} (P, f) [37]:

$$L_{sum}\ (\mathrm{P}, \mathrm{F}) = \sum_{(i,\ j) \in P} \left[\left(\frac{(f(i) + f(j)}{2} \right) \cdot l(i, j) \right] \quad (1)$$

where $f(i)$ and $l\ (i, j)$ indicate the value of cell i on surface f and the straight-line distance between the centers of cells i and j, respectively.

3.3. Creating a Walkability Index

The walkability index was generated using a multi-criteria approach, a method that evaluates several factors simultaneously within a GIS environment [37]. This index was then used to generate a cost surface that represents the relative cost of traversing different areas in the city center. The cost surface can be created by assigning cost values to each cell in a raster grid based on the criteria defined in the previous paragraph [15,43]. A multi-factor cost surface was created to find pedestrian-friendly paths in the city center. This involved creating a distance raster for heritage sites, green spaces, mosques, commercial areas, and vacant parcels and providing scores from 1 to 10 based on proximity.

Street slopes were ranked from 1 to 10 based on their steepness according to guidelines mentioned in [44,45]. Street activity levels were categorized as mixed (1), moderately mixed (4), mostly residential (7), or inactive (10). Using the Analytical Hierarchy Process (AHP), we assigned weights to these factors and combined them using weighted overlay analysis [12] to create the final cost surface. Weighted overlay analysis is a spatial analysis technique that combines multiple thematic layers of geographic data, assigning different levels of importance or weight to each layer. Each layer represents a different variable

or factor, and by assigning weights, the influence of each on the overall analysis can be prioritized.

3.3.1. Creating a Distance Raster

Next, we create a distance raster that represents the proximity of each cell in the study area to the desired variable [37]. The distance raster grids for the study variables (heritage sites, green areas, commercial sites, mosques, and vacant parcels) and the classification of street activities and street slopes are shown in Figure 3.

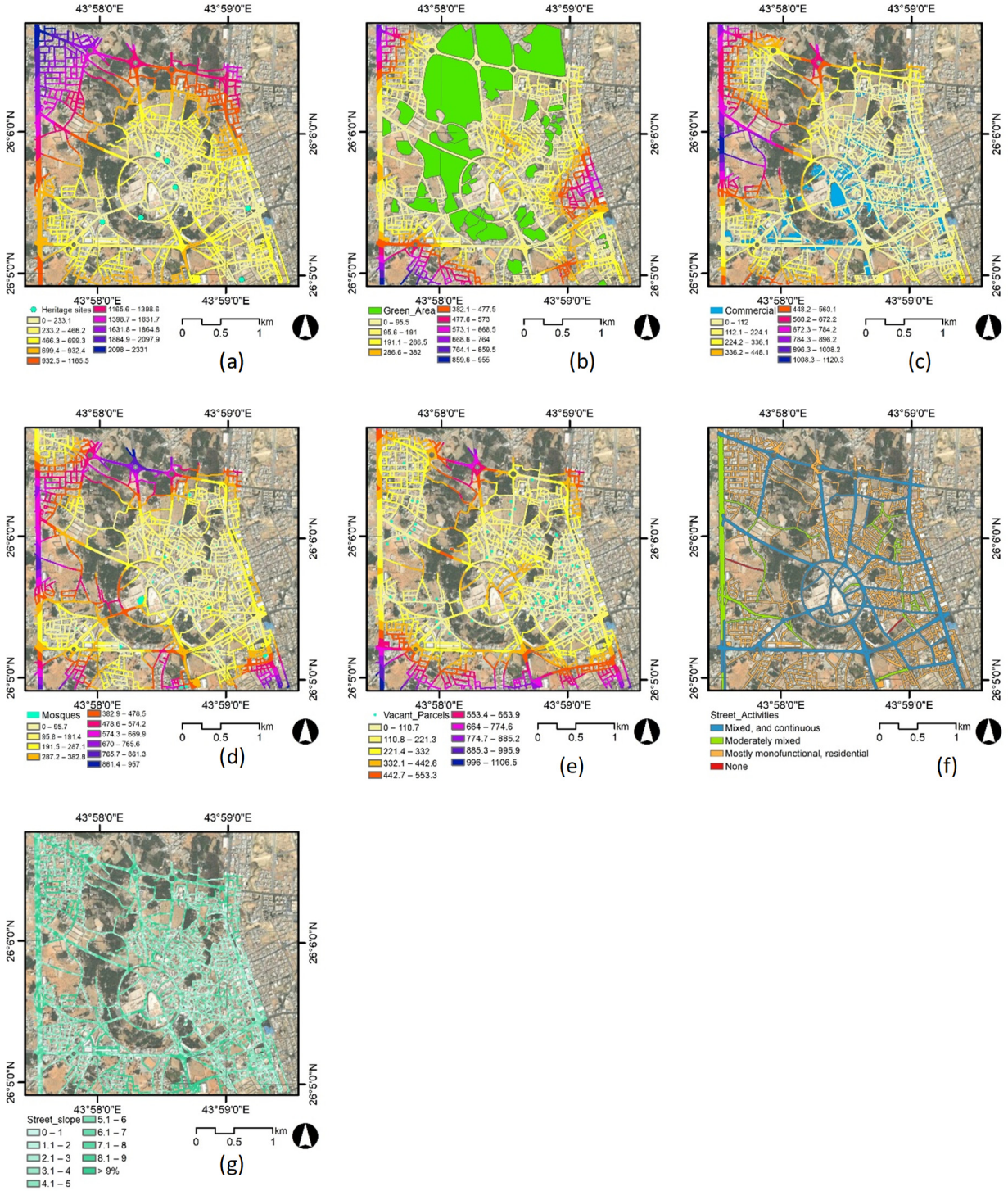


Figure 3. Distance grids around walkability criteria: (**a**) heritage sites, (**b**) green areas, (**c**) commercial sites, (**d**) mosques, (**e**) vacant parcels, (**f**) street activities, and (**g**) street slopes. [Source: the authors].

3.3.2. Ranking the Distance

Once the distance raster grids were generated, the distance values were ranked on a scale from 1 to 10, where 10 represents the highest-cost-value locations or those that are less attractive for walkability [27,37]. The ranked raster grids are shown in (Figure 4). The ranking process plays a crucial role in unlocking the potential of the assigned values. By prioritizing these values, the overlay analysis can effectively combine them. This allows us to identify areas where low values from multiple factors coincide, revealing locations with the most favorable characteristics.

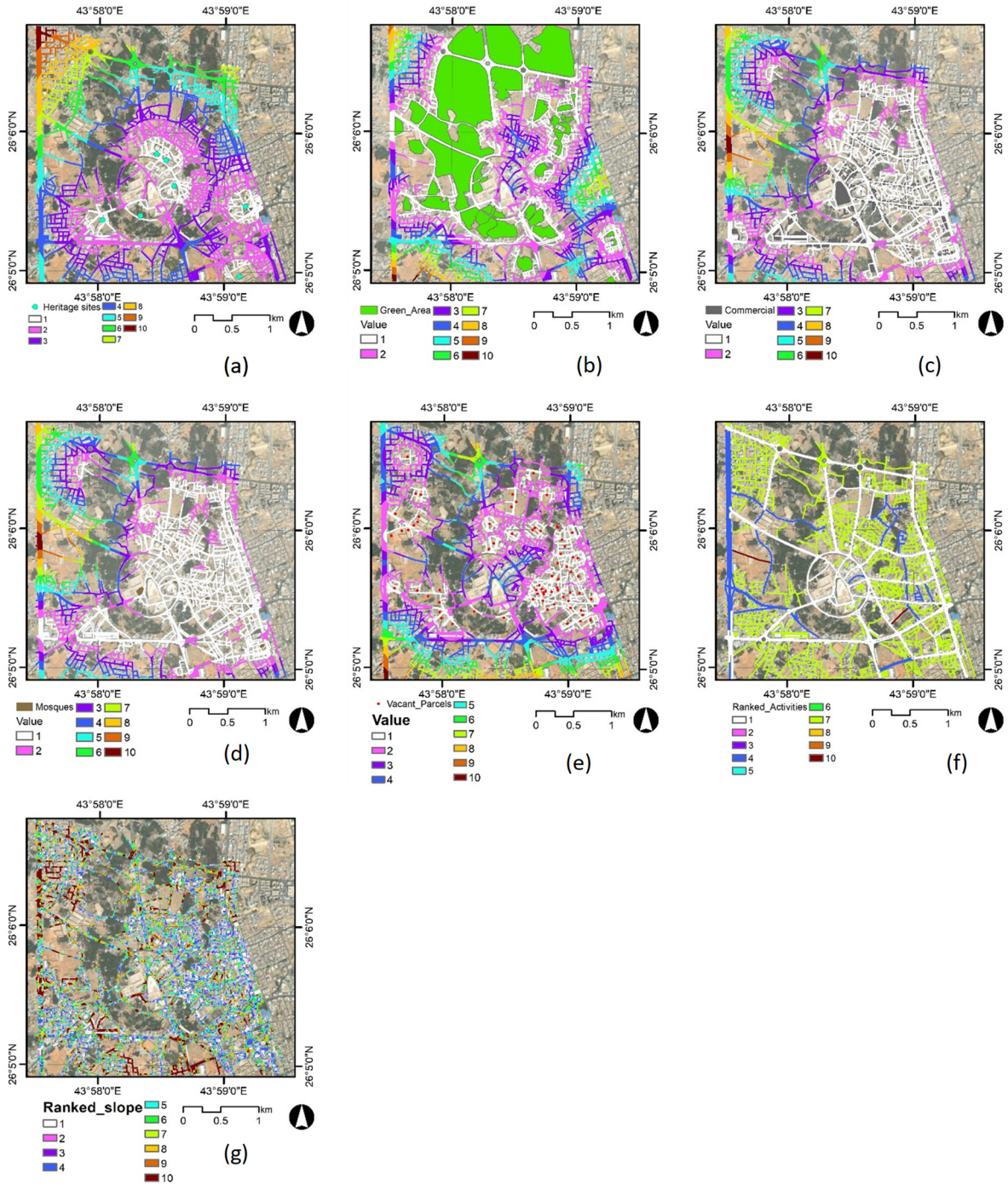


Figure 4. Ranked distance grids around walkability criteria: (**a**) heritage sites, (**b**) green areas, (**c**) commercial sites, (**d**) mosques, (**e**) vacant parcels, (**f**) street activities, and (**g**) street slopes. [Source: the authors].

3.3.3. The Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) is a structured technique for making complex decisions. The approach, developed by Saaty [46], begins with establishing a structure of criteria and elements and organizing them into a hierarchical system. It excels in situations where multiple criteria influence the outcome, and these criteria can be subjective or difficult to quantify. After defining the criteria and through a series of pairwise comparisons, the relative importance of criteria and how well each option fulfills those criteria can be assessed. This systematic approach translates subjective judgments into numerical values, allowing for the calculation of a final score for each option. For comparison, each criterion is evaluated in terms of each category by awarding values between (1) and (9). Table 1 shows the scale and their respective value descriptions.

Table 1. The scales for pair-wise comparisons. Adopted from [46].

Scales	Degree of Importance	Descriptions
1	Equal	The two criteria are equally important to the other pairs
3	Moderate	The criteria are slight to moderately more important
5	Strong	The criteria are much more important or essential
7	Very strong	The criteria are strongly favored over the other pairs, and this is shown in practice
9	Extremely strong	The criteria are undeniably favored over the other pairs, and this is shown in practice
2, 4, 6, 8	Intermediate values	Used to represent intermediate values between degree 1, 3, 5, 7, and 9

3.3.4. Weight the Criteria

Once the criteria were set, we commenced a pair-wise comparison matrix [A] using the scale shown in Table 1. The factors for each level and their weights are A_1, A_2, . . ., A_n and W_1, W_2, . . ., W_n.

The importance value of a_i and a_j is shown as a_{ij}. The pair-wise comparison matrix of factors A_1, A2, . . ., An as A = [a_{ij}] is presented as follows [47]:

$$\mathbf{A} = (a_{ij})_{\,n\ x\ n} \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix} \quad (2)$$

In the matrix, the element $a_{ij} = 1/a_{ji}$; thus, when i = j, $a_{ij} = 1$. The matrix was normalized using the equation

$$a'_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \quad (3)$$

where ij = 1, 2, 3 . . .. . . n.

Finally, the weights of the criteria can be computed using the following formula:

$$w_i = \frac{\sum_{i=1}^{n} a'_{ij}}{n} \quad (4)$$

where w_i is the total weight of the criterion.

In this research, the analysis conducted through pairwise comparisons using the AHP method revealed the following priorities for the criteria studied: heritage sites were deemed highly important, with a weight of 33.0%, followed by green areas at 20.6%. Next were street activities with a weight of 17.6%, followed by commercial sites at 9.5%. The remaining three criteria received the following weights: mosques at 8.7%, street slopes at 5.9%, and vacant

parcels at 4.7%. These weights can assist decision makers and planners in reevaluating the city center of the study area and allocating resources to enhance walkability by prioritizing actions and investments according to the relative importance of each criterion. Figure 5 shows the priorities of the studied criteria as driven using an AHP calculator.

Priorities

These are the resulting weights for the criteria based on your pairwise comparisons:

Cat		Priority	Rank	(+)	(-)
1	Heritage	33.0%	1	12.9%	12.9%
2	Commercial sites	9.5%	4	4.0%	4.0%
3	Green area	20.6%	2	8.1%	8.1%
4	Mosques	8.7%	5	2.6%	2.6%
5	Activities	17.6%	3	6.1%	6.1%
6	Slope	5.9%	6	2.0%	2.0%
7	Vacant	4.7%	7	2.0%	2.0%

Figure 5. Priorities of studied walkability criteria. [Source: the authors].

3.3.5. Checking the Consistency

Additionally, the AHP promotes consistency in decision making by verifying pairwise comparisons for logical consistency [46].

Within the AHP framework, the assessment of consistency is carried out through the use of the consistency ratio (CR). The CR is determined by comparing the consistency index (CI) with an average random consistency index (RI). The consistency ratio and the CI are defined by Equations (5) and (6), as follows:

$$CR = \frac{CI}{CR} \tag{5}$$

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{6}$$

where CI represents the consistency index, λ_{max} is the primary or principal eigenvalue of the matrix (and is calculated from the matrix), and n is the matrix's number of factors. The average random consistency index (RI) [42] is also derived from these factors. Table 2 shows the value of RI based on the number of factors (N).

Table 2. Random consistency index (RI) [27].

N (Number of Factors)	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

In the AHP, a CR result below 0.1 is deemed acceptable, while a result exceeding this threshold leads to rejection [42]. In this study, the CR for all comparisons was below 0.1, signifying its suitability for the AHP analysis.

Figure 6 shows the relationship between the walkability index and various factors, such as the number of pedestrians, the presence of sidewalks, and the availability of public transportation. The graph is likely used to support the research objectives of the study.

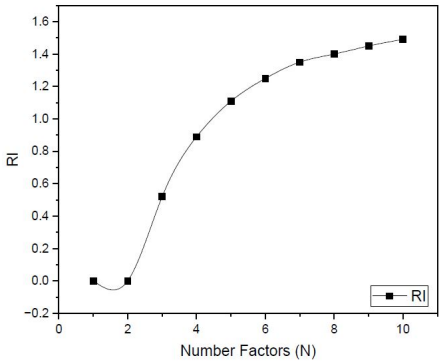


Figure 6. Factor for the walkability index in Onaizah City. [Source: the authors].

4. Results

The walkability index provides insights into the relative ease associated with walking in different areas of the city center, considering the defined criteria [11]. It serves as a visual representation of the varying levels of walkability based on the assigned weights and ranked distances. Figure 7 shows the walkability index in the study area on a scale of 1 to 8 and uses a color gradient or shading scheme, where different colors represent varying levels of walkability. Areas represented with high numbers and darker or more intense colors indicate greater challenges or barriers to pedestrian movement. Conversely, areas with a lower number are represented with lighter or less intense colors, suggesting more favorable conditions for walking.

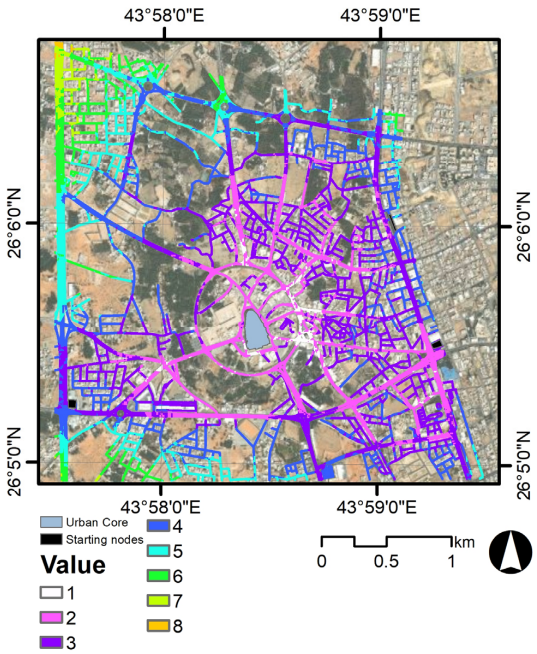


Figure 7. Walkability index of the study area. [Source: the authors].

The walkability index was used as the cost surface raster and the least-cost paths were generated from three start points to the city center as the destination point. The results are shown in Figure 8 and Table 3.

The walking urban corridors start from different pedestrian accessibility points and all end at the urban core, with its sidewalks along with the internal ring road. These offer pedestrians from many locations in the city with opportunities for walking to a wide sector of Onaizah. All urban corridors are with reasonable range of this, between 1335 and 1937 m, which aligns with 15–20 min' time-based walking [32] distance (if the distance of 400 m is subtracted at the end of path number 3, as the urban core has many gates from

which to enter). This finding aligns with the previous research that emphasizes the positive relationship between shorter walking distances and increased pedestrian activity. The walkability analysis, based on the walkability index, also provides insights into the factors influencing the least-cost path.

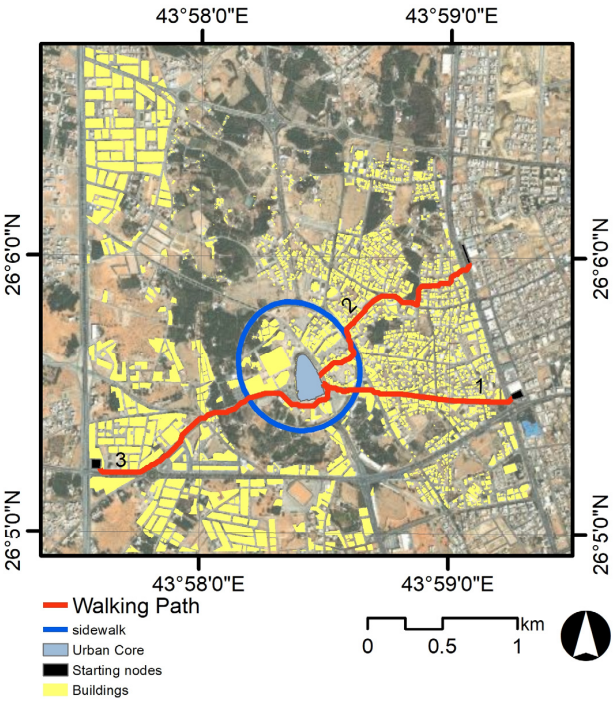


Figure 8. The result of multi-criteria decision-analysis methods to identify urban corridors throughout Onaizah city center (1, 2 and 3) and its compatibility with proposed municipal upgrading strategic project for urban core's pedestrian infrastructure. [Source: the authors].

Table 3. Lengths of the three urban corridors inferred from walkability analyses in the study area and its measurements by TBW [33].

Urban Corridor No.	Length (m)	TBW Figure (Minute) (Walking Speed: 400 m/5 min)
1	1335	17 (approx.)
2	1624	20 (approx.)
3	1937	24 (approx.)

The study successfully employed multi-criteria and cost distance analysis calculation to infer the least-cost path, which represents the most efficient and cost-effective route for pedestrians within time-based walkability (approx. 15 min from starting nodes to crossing points with the sidewalks along with internal ring road). The integration of GIS techniques proved to be instrumental in analyzing street networks and assessing walkability in Onaizah City. The findings are as follows:

- Heritage sites were given the highest weight of 33.0%. This indicates that preserving and enhancing the accessibility to heritage sites is crucial for promoting walkability in Onaizah City. The cultural and historical context of the city plays a significant role in improving the pedestrian experience and creating a vibrant urban environment.
- The availability and suitability of green spaces was set at 20.6%. This highlights the importance of linking parks and other green spaces in urban planning to enhance walkability. Green areas contribute to the overall pedestrian experience by providing green spaces that are more attractive for walking.

- Through the results of the study, the rest of criteria received weights in relative importance and less than green areas and heritage areas. The street activity that encourages people to walk received weight of 17.6%; mosques and commercial sites received almost equal weights, indicating their roles in the urban fabric. Mosques serve as important community spaces, and commercial sites contribute to the city's vitality and economic activity.
- The urban corridors obtained from the results of the applied study point to an integral relationship with the urban core of the city of Onaizah, which is surrounded by pedestrian sidewalks along the inner ring road of the area; this forms a network of urban corridors that promote pedestrian walkability at the city center. The urban corridors that are derived here intersect with the urban ring road corridor at points that constitute pedestrian access points. These support the pedestrian infrastructure of the Onaizah Municipality Urban Development Project [31].
- The results of this study provide a better understanding of walkability in the city of Onaizah and provide insight for evidence-based decision making in the urban planning process. Through GIS analyses and assessing the relative importance of different criteria, planners and decision makers can identify priorities that are consistent with enhancing walkability, including improving pedestrian infrastructure, providing green spaces, and emphasizing the preservation and accessibility of heritage sites, and this reflects the notion of nature-based solutions (NBSs) and time-based walking distance methodologies [29–32].

5. Discussion

The research examines various approaches that promote walkability, addressing theories that emphasize the efficiency of pedestrian facilities. It focuses on the 15 min city concept and nature-based solutions (NBSs) for urban sustainability. The study evaluates the criteria and factors influencing the selection of suitable urban corridors and explores ways of enhancing the walkability features in the city center of Onaizah.

The AHP methodology applied in this research enhances the decision-making process by systematically evaluating multiple walkability criteria and assigning weights to factors such as proximity to heritage sites, green areas, and street activity. By integrating these weighted factors through GIS, AHP improves the accuracy and relevance of the final walkability index, which in turn facilitates better urban planning decisions. Additionally, the pairwise comparison in AHP adds transparency and justifiability to the criteria ranking process, ensuring that the most impactful factors for enhancing walkability are prioritized.

The study highlights the importance of preserving built environment elements, such as heritage sites, and suggests integrating green areas while considering commercial sites and mosques within the NBS framework. Social activities, land profiles, vacant lands, and time-based walking strategies are also examined. Climatic factors, such as temperature and conditions affecting the pedestrian environment, are considered constants that future studies should address.

Three urban corridors (1335, 1624, and 1937 m in length) were generated using GIS techniques. These corridors are divided into two stages: the first extends from the access point to the inner pedestrian ring road, and the second extends from the culvert crossing to the urban core around Onaizah Mall. This design encourages walkable distances within urban corridors, improves accessibility, and promotes a healthier lifestyle, contributing to a vibrant urban environment.

The resulting weights for the selected analysis for seven criteria based on pairwise comparisons, as follows:

1. By incorporating various elements—such as pedestrian-friendly design, connectivity, mixed-use development, green spaces, public art and cultural installations, safe and inviting atmospheres, and mixed-use development—heritage sites and buildings can greatly enhance walkability in urban corridors that lead to the city center. Incorporating walkability elements into historic buildings and sites preserves cultural uniqueness while promoting lively, accessible urban corridors that improve city dwellers' quality of life.

2. Buildings and commercial sites can greatly improve walkability in urban corridors that lead to the city center by incorporating a variety of characteristics, such as connectivity, pedestrian-friendly design, mixed-use developments, public spaces and amenities, traffic-calming measures, and events and activities. Commercial properties and buildings can create lively urban corridors that encourage foot traffic and help make cities healthier and more cohesive for their citizens by implementing these walkability elements.
3. Through integrating several customized features, including climate adaptation, aesthetic enhancements, environmental benefits, safety and comfort, connectivity and accessibility, community spaces, and encouragement of active lifestyles, landscaped areas in Saudi Arabian cities can significantly improve walkability in the urban corridors that lead to the core of the cities. By doing so, they create lively, viable urban corridors which enhance residents' quality of life.
4. By incorporating a number of essential elements, such as strategic location, pedestrian-friendly design, community gathering spaces, integration with urban corridors, safety and security, active areas, cultural and spiritual significance, and encouragement of active lifestyles, religious buildings—the mosques in Saudi Arabian cities—can effectively promote walkability in urban corridors leading to the core of the cities. Mosques play a critical role in boosting walkability in urban corridors across Saudi Arabian cities, fostering lively and connected neighborhoods. They achieve this by improving mosques through the accessibility, safety, and community participation of urban corridors.
5. Through a variety of features, including community events, social spaces, cultural activities, recreational opportunities, accessibility to social amenities, family and community engagement, safety and comfort, and accessibility to social amenities, daily social activities in Saudi Arabian cities can significantly promote walkability in urban corridors leading to the core of cities. Daily activities greatly improve walkability in Saudi Arabian cities' urban corridors by promoting social contact and community involvement, resulting in a livelier and more integrated urban environment.
6. Through a range of features—including gentle slopes, effective drainage, landscaping and green spaces, integration with urban design, safety considerations, and encouragement of active lifestyles—land profile and street slope in Saudi Arabian cities (with Onaizah as a case study here) can significantly promote walkability in urban corridors leading to the core of cities. Urban planners in Saudi Arabia can create accessible, safe, and attractive corridors that connect households to the core of cities by skillfully utilizing land profile and controlling street slopes.
7. Vacant land in Saudi Arabian cities has a lot of potential to encourage walkability along the urban corridors that connect to the city center. By leveraging the potential of vacant plots, urban planners in Saudi Arabia can enhance walkability, creating vibrant, connected urban corridors that improve access to the core of cities and enrich residents' lives. These improvements can be accomplished through the development of green spaces, mixed-use projects, pathway and connectivity enhancements, community engagement, improved safety and comfort, cultural and historical integration, and sustainable practices.

For users, having the ability to walk through urban corridors that lead to the core of cities has numerous key benefits, including—but not limited to—the following:

- Health benefits in regard to both mental and physical health.
- Environmental impacts in terms of lower emissions and biodiversity.
- Economic advantages are possible, where such changes will boost property values in Onaizah, a medium-sized Saudi city, and demand support from nearby businesses.
- Social connectivity can be achieved through creating walkable neighborhoods that promote social interaction and a sense of community while boosting foot traffic; this may create safer streets as a consequence of community engagement.
- Accessibility can be promoted by implementing multimodal transit and accessible mobility measures.

- Urban design and aesthetics can be leveraged through the creation of attractive spaces; well-planned avenues with greenery and amenities enhance a city's aesthetic appeal while promoting its unique cultural character.
- Cultural identity can be promoted through the creation of walkable areas that showcase local culture and history through art, architecture, and community events.

Walkable urban corridors strengthen communities overall, benefiting individual users while making cities more vibrant, sustainable, and inclusive. Following these recommendations, Table 4 presents a correlation matrix illustrating the benefits of walkability for Saudi urban areas, based on the Onaizah case study. The urban benefits associated with the Onaizah City center case study, which serves as a model for medium-sized cities in the Kingdom of Saudi Arabia, are correlated with 7 qualitative categories and divided into 60 specific factors to assess urban corridors in the central area.

Table 4. A correlation matrix illustrating the benefits of walkability for Saudi City's urban areas (based on the Onaizah case study). [Source: the authors].

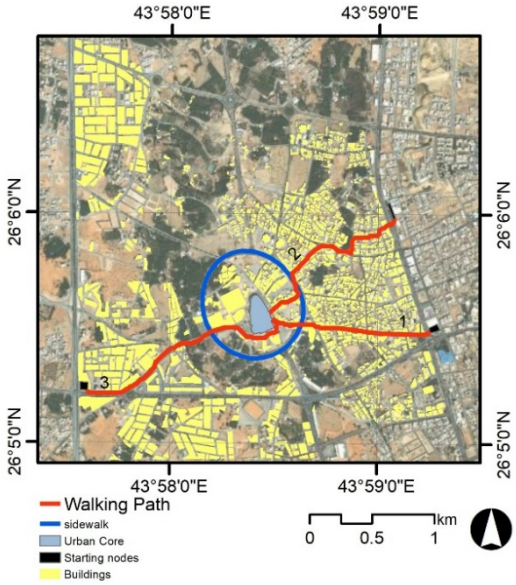
Urban Corridors Walkability Features in Saudi Arabian Cities (Onaizah City Case Study)			Numerous Urban Benefits of Walkability Features in Urban Corridors						
			Health Benefits	Environmental Impact	Economic Advantages	Social Connectivity	Accessibility	Urban Design and Aesthetics	Cultural Identity
									
Cat. (1)	Heritage Sites	1. Pedestrian-Friendly Design	●	●		●		●	
		2. Connectivity			●	●	●		
		3. Mixed-Use Development			●		●		
		4. Green Spaces	●	●		●			
		5. Public Art and Cultural Installations			●	●		●	●
		6. Safe and Inviting Atmosphere	●	●		●			●
		7. Active Frontages			●	●		●	
Cat. (2)	Commercial Sites	8. Mixed-Use Developments			●	●	●		
		9. Pedestrian-Friendly Design	●	●		●		●	●
		10. Connectivity			●	●	●		
		11. Traffic-Calming Measures				●	●		
		12. Public Spaces and Amenities	●	●	●	●			●
		13. Sustainable Practices	●	●					

Table 4. *Cont.*

Urban Corridors Walkability Features in Saudi Arabian Cities (Onaizah City Case Study)			Numerous Urban Benefits of Walkability Features in Urban Corridors						
			Health Benefits	Environmental Impact	Economic Advantages	Social Connectivity	Accessibility	Urban Design and Aesthetics	Cultural Identity
Cat. (3)	Green Area (Landscaped)	14. Shade Provision	●	●		●			
		15. Cooling Effects	●	●		●			
		16. Aesthetic Enhancements		●		●		●	●
		17. Environmental Benefits	●	●		●		●	
		18. Safety and Comfort		●		●			
		19. Connectivity and Accessibility		●		●	●		
		20. Public Gathering Areas			●	●	●		●
		21. Event Venues				●	●		
		22. Encouragement of Active Lifestyles	●		●	●			●
Cat. (4)	Religious (Mosques)	23. Strategic Location		●	●		●	●	
		24. Pedestrian-Friendly Design	●	●	●	●			●
		25. Community Gathering Spaces			●	●	●		●
		26. Integration with Urban Corridors			●	●		●	
		27. Safety and Security	●		●	●	●	●	
		28. Cultural and Spiritual Significance				●		●	●
Cat. (5)	Social Activities	29. Community Events			●	●		●	●
		30. Cafés and Restaurants			●	●		●	
		31. Public Parks			●	●		●	
		32. Cultural Activities			●	●		●	●
		33. Recreational Opportunities				●			
		34. Accessibility of Social Amenities				●	●	●	●
		35. Family and Community Engagement	●			●			
		36. Safety and Comfort	●			●	●	●	

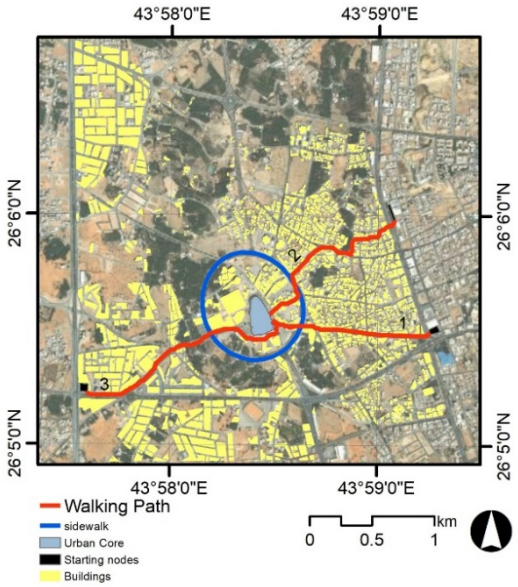
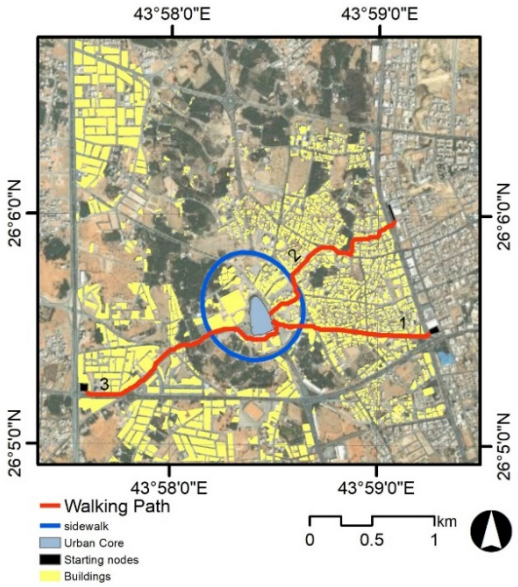


Table 4. *Cont.*

Urban Corridors Walkability Features in Saudi Arabian Cities (Onaizah City Case Study)				Numerous Urban Benefits of Walkability Features in Urban Corridors						
				Health Benefits	Environmental Impact	Economic Advantages	Social Connectivity	Accessibility	Urban Design and Aesthetics	Cultural Identity
Cat. (6)	Slope (Land Pro-file)	37.	Outdoor Gatherings		●	●	●		●	
		38.	Social Spaces	●	●		●			
		39.	Cultural Activities				●			●
		40.	Recreational Opportunities	●		●	●	●	●	●
		41.	Accessibility of Social Amenities				●	●	●	
		42.	Neighborhood Events			●	●			●
		43.	Well-Lit Areas	●			●		●	
		44.	Active Streetscapes	●	●	●		●	●	
		45.	Gentle Slopes					●		
		46.	Enhanced Accessibility	●		●	●	●		
		47.	Landscaping and Green Spaces		●	●	●	●		
		48.	Integration with Urban Design	●	●			●		
		49.	Safety Considerations	●	●	●	●			
		50.	Encouragement of Active Lifestyles				●		●	●
Cat. (7)	Vacant Lands	51.	Development of Green Spaces		●	●	●			
		52.	Pocket Parks		●	●	●	●	●	
		53.	Mixed-Use Developments		●		●	●	●	
		54.	Cultural Venues			●	●			●
		55.	Pathway Connectivity Enhancements		●		●	●	●	●
		56.	Markets and Pop-Up Events			●	●	●		
		57.	Improved Safety and Comfort	●	●	●	●	●	●	●
		58.	Cultural and Historical Integration				●			●
		59.	Community Gardens		●		●			
		60.	Green Infrastructure		●			●		
Frequently check for walkability features of the selected study categories (Sum./%)				**22**	**27**	**30**	**53**	**27**	**26**	**21**
				37	**45**	**50**	**88**	**45**	**43**	**35**

The indicated categories depend on the selected physical ones for analysis in Onaizah city center.

The most significant category is societal benefits, which highlights the importance of encouraging users to walk through urban corridors with an 88% correlation (53 of the 60 factors). This is followed by economic benefits, ranking second with a 50% correlation (30 of the 60 factors). In third and fourth places are the environmental benefits and the impact of religious buildings (mosques and their immediate surroundings), which correlate with 45% of the factors (27 of the 60). Enhancing urban scenery and aesthetics ranks fifth, with a 43% correlation (26 of the 60 factors). The correlation for users' overall health ranks sixth with a 37% correlation (22 of the 60 factors), and the cultural identity of the Onaizah City Center ranks last, with a 35% correlation (21 of the 60 factors).

In conclusion, based on the findings of the Onaizah case study, Saudi Arabian communities aim to enhance residents' societal quality, reduce environmental impact, and improve the long-term health of both cities and citizens by promoting walkability features.

6. Conclusions

This study focuses on enhancing walkability in Onaizah City through a systematic methodology using GIS methods, offering a strong foundation for evidence-based decision making in urban planning. By leveraging GIS and carefully evaluating various criteria, urban planners and legislators can prioritize investments that support walkability, which brings numerous social and environmental benefits. The study presents a visual representation of the suitability of urban corridors for walkability in Onaizah, offering a valuable tool for urban planners and stakeholders in planning future pedestrian urban corridors. Unlike other studies, this research highlights the importance of heritage sites, commercial sites, green spaces, and mosques, which were identified through a multi-criteria GIS approach as critical factors for walkability.

This study provides a graphic representation of the suitability of walkable urban corridors in Onaizah City. The resulting map holds significant value as a tool for urban planners and stakeholders, aiding in the identification and planning of future pedestrian routes. In contrast to other research, this study emphasizes that the investigation of four important variables—heritage sites, commercial sites, green spaces, and mosques—is necessary in determining whether a location is suitable for walking, as determined by a multi-criteria method in a GIS context.

Currently, Onaizah's environment lacks adequate walkability, spaciousness, and social interaction. The time-based approach revealed that, within a 10–15 min walking distance, all selected locations were accessible from the proposed urban corridors. These corridors connect the city's core to its center, enhancing walkability. The final model of urban corridors was developed using GIS methods and multi-criteria decision analysis, incorporating the principles of the time-based walkability approach. Future research aims to explore six additional criteria, including safety, comfort, sociability, and livability, to further improve walkability in Onaizah, while this study considered microclimate factors impacting walkability in Onaizah. The findings are intended to be used by urban planners, municipalities, and decision makers.

In terms of generalizability, the study's conclusions are specific to Onaizah City and may not be immediately applicable to other locations due to its unique cultural, geographical, and infrastructural contexts. Caution should be exercised when extending these results to other areas. Future research should aim to validate and adapt the findings to different locations, particularly within medium-sized cities in Saudi Arabia.

7. Recommendations

- In terms of future outlook, the present research recognizes the importance of studying the treatments of urban corridors from the perspective of factors that affect their relationships with the city center; this perspective will enable the activation of the walking pattern. Such factors include physical and non-physical factors related to urbanization.
- Future research can conduct comparative studies across multiple Saudi Arabian locales or in similar contexts. This can provide insights into the similarities and differences

in walkability factors and their relative importance in different regions. Comparative studies can help identify common patterns and robust findings that can guide urban planning efforts on a broader scale.

- Assess the impact of interventions: It would be valuable to conduct longitudinal studies that evaluate the impact of specific interventions that aim to enhance walkability. By implementing targeted interventions such as infrastructure improvements, pedestrian-friendly policies, or community engagement initiatives, researchers can measure the effectiveness of these interventions in improving walkability. This can provide evidence-based recommendations for future urban planning and policy initiatives.
- Integrate emerging technologies: With the rapid advancement of technology, future research can explore the integration of emerging technologies such as augmented reality, mobile applications, and smart city solutions in assessing and enhancing walkability. These technologies can provide real-time data, interactive mapping tools, and personalized recommendations to improve the pedestrian experience and promote sustainable mobility.

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Conflicts of Interest: The authors declare no conflicts of interest.

Nomenclature

AHP	Analytical Hierarchy Process
CBD	central business district
CR	consistency ratio
DEM	digital elevation model
GIS	Geographic Information System
LCP	least-cost path
NBS	nature-based solutions
RI	random consistency index
SRTM	Shuttle Radar Topography Mission
TBW	time-based walkability approach
BWh	hot desert climates
DEM	digital elevation model
MOMRA	Ministry Of Municipalities and Rural Affairs, Kingdom of Saudi Arabia

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