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Assessing Green Roof Accessibility for the Disabled Community in High-Rise Residential Buildings

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Abstract
Green roofs provide significant environmental, social, and aesthetic benefits. In high-rise residential buildings, green roofs offer communal spaces for recreation. However, despite their growing adoption as a sustainable development strategy, accessibility is often overlooked, limiting their potential to support social sustainability. Hence, access for the disabled community remains a critical concern. Residential green roofs have been largely overlooked in Malaysia, as previous access audits have primarily concentrated on public and commercial buildings. The study evaluates the accessibility of green roofs in three high-rise residential buildings in Shah Alam, Malaysia, in order to resolve this gap. The *Universal Design Assistant* (UD-AI) tool was utilized to support a qualitative approach with an access audit that was in accordance with the Malaysian Standard MS 1184:2014. The audit identified numerous obstacles, such as inadequate signage, steep incline gradients, and restricted access to communal amenities. Fostering inclusive and resilient urban environments necessitates overcoming these obstacles. The findings provide practical guidance for policymakers, designers, and facility managers to enhance the accessibility of green roofs and promote social sustainability in high-rise residential developments.

1.0 INTRODUCTION

Cities worldwide are being progressively impacted by the increasing environmental challenges of deforestation, global warming, climate change, air pollution, energy scarcity, and frequent natural disasters. Rapid urbanization has contributed to these issues, resulting in substantial environmental and socioeconomic concerns in urban areas. As the number of green spaces decreases and the number of construction projects increases, building professionals are increasingly utilizing green roofs and wall facades as solutions (Rahman et al., 2023). Green roofs have been a global practice for more than a century and are now acknowledged as a critical element of urban greening (Ismail et al., 2015). High-rise residential buildings often incorporate green roofs due to limited available land, utilizing podiums, parking areas, and rooftops for gardens and other attractions to maximize space and improve urban environments (Rahman et al., 2023).

Although substantial scientific research has been conducted to evaluate the cooling efficacy, efficiency, and plant survival rates of green roofs (Ismail et al., 2015), there is still a significant lack of understanding regarding their importance in the social sustainability dimension. In Malaysia, green roofs are commonly integrated into high-rise residential buildings and are often used as social spaces. However, there is a significant gap in research concerning the accessibility of these green roofs, particularly for the disabled community, especially wheelchair users. While previous access audits in Malaysia have focused on other building types, green roofs in residential settings remain largely unexamined.

Therefore, this study fills an important gap by conducting an access audit tailored to these elevated communal environments. This study aims to assess the accessibility of intensive green roofs in high-rise residential buildings. It identifies existing barriers and provides recommendations to improve accessibility by employing a structured observational method guided by an access audit checklist that is in accordance with the Malaysian Standard – MS 1184:2014 Universal Design and Accessibility in the Built Environment – Code of Practice (Second Revision) (Department of Standards Malaysia, 2014).

2.0 GREEN ROOFS ACCESSIBILITY AND SOCIAL SUSTAINABILITY

To examine the relationship between green roof accessibility and social sustainability, it is essential to understand what green roofs are and the benefits they offer. This understanding provides the foundation for exploring how green roofs can contribute to social sustainability, particularly in relation to the disabled community, and how accessibility can be ensured by identifying and addressing physical barriers.

2.1 Green Roofs

Green roofs, which are also referred to as vegetated, eco, or living roofs, are roofs that are covered in vegetation that is cultivated on a growing medium or substrate. Green roofs consist of several components, including vegetation, substrate, filter mats, drainage materials, root barriers, and insulation (Vijayaraghavan, 2016). In Malaysia, green roofs are classified into two primary categories: extensive and intensive (Rahman et al., 2023; Zhang et al., 2024). For drought-tolerant plants such as sedums, mosses, and herbs, extensive green roofs with a modest growing medium ranging from 50 to 150 mm are an appropriate choice. These are particularly well-suited for structures with restricted structural capacity and necessitate minimal upkeep.

Conversely, intensive green roofs are characterized by a more complex growing medium that facilitates a wider variety of vegetation, such as crops, trees, and shrubs (Zhang et al., 2024). Their layered construction includes waterproofing, root barriers, drainage, filter layers, and soil with high water and nutrient retention. With depths ranging from 200 mm to 2000 mm, they can support more complex ecosystems (Du et al., 2010). Due to their higher structural load requirements, intensive green roofs are primarily suited for new constructions and offer several advantages, including diverse planting possibilities, improved user accessibility, superior thermal insulation, and enhanced aesthetic appeal.

Both extensive and intensive green roofs are not always situated at the highest level; some are constructed on podium decks or intermediate levels (Townshend & Duggie, 2007) and may resemble ground-level gardens. They are structurally incorporated into the building and function as rooftops for underlying structures, including parking facilities, residential units, or shared facilities.

In densely populated areas, green roofs have become an essential component of urban green infrastructure as a result of their extensive environmental, economic, and social advantages (Rahman et al., 2023; Shafique et al., 2018). Environmentally, green roofs contribute to the improvement of air and water quality, the mitigation of the urban heat island (UHI) effect, and the improvement of runoff management. Zhang et al. (2024) discovered that green roofs can substantially enhance rainwater retention and reduce roof surface temperatures by 0.02°C to 30°C. In terms of economics, they contribute to energy efficiency by decreasing interior temperatures, which in turn reduces the need for building cooling. Jia et al. (2024) underscore the cost-effectiveness of green roofs as a sustainable development strategy, as they can provide long-term energy savings.

In addition to their economic and environmental advantages, green roofs offer substantial social advantages. These encompass enhanced urban aesthetics, recreational opportunities, and improved mental and physical well-being. The psychological advantages of green roofs are also emphasized in the promotion of mental wellness and relaxation through interaction with nature (Rahman et al., 2023; Sundara Rajoo et al., 2021; Mesimäki et al., 2019). Furthermore, de Oliveira Santos et al. (2024) observe a growing research emphasis on the optimization of green roof design to enhance these combined benefits, thereby reinforcing their relevance as a comprehensive solution to urban challenges.

2.2 The Role of Green Roofs in Promoting Social Sustainability

The value of green infrastructures, including green roofs, is on the rise due to their contributions to sustainability, visual appeal, and individual well-being (de Oliveira Santos, 2024). Green roofs, which function as leisure spaces in urban environments, offer tenants and visitors a pleasant environment in which to unwind, interact with nature, and promote social interaction. By providing opportunities for tension relief and recreation, these spaces promote mental wellness when they are made accessible. Rahman et al. (2023) emphasize that psychological health is considerably improved by both visual and physical engagement with greenery. In a similar way, Gidlöf-Gunnarsson and Öhrström (2007) observe that exposure to green spaces can alleviate tension and even promote physical health outcomes, such as weight management.

Green roofs also contribute to social sustainability by improving livability by providing mental and emotional benefits. While visiting rooftop gardens, Mesimäki et al. (2019) noted that numerous individuals reported experiencing a profound sense of tranquility and a profound connection to nature. These gardens provide rejuvenating experiences for individuals who work in high-pressure environments. Additionally, Sundara Rajoo et al. (2021) discovered that urban green spaces, such as green roofs, functioned as therapeutic interventions during the COVID-19 pandemic, assisting individuals in preserving their mental health during periods of crisis. Collectively, these results emphasize the essential function of green roofs in the promotion of holistic health and social sustainability in urban environments.

Nevertheless, Ali Ariff et al. (2023) emphasize that, in the current urban context of Malaysia, green roofs are primarily perceived as an exclusive architectural feature that is intended to promote sustainable building strategies, rather than being integrated as accessible public spaces with a broader social potential. This perception restricts their ability to promote inclusive urban environments and disregards the potential for green roofs to function as shared communal spaces that benefit a broader population, including the disabled community. Yet, accessibility is fundamental to the promotion of sustainable development and is a critical element of social sustainability (Dempsey et al., 2011).

2.3 Accessibility for the Disabled Community's Inclusion

Access to the built environment is a fundamental human right that ensures everyone, including the disabled community, can participate fully in society (Frías-López & Queipo-de-Llano, 2020; Zahari et al., 2023). Article 30 of the Convention on the Rights of Persons with Disabilities (CRPD) affirms the right of persons with disabilities to engage in cultural life, recreation, and leisure, while Malaysia's Persons with Disabilities Act 2008 reinforces the need to eliminate environmental barriers (United Nations, 2006; Malaysian Government, 2008). Despite the existence of legal frameworks, the disabled community continues to face significant design-related barriers in the built environment (Bailey et al., 2015; Kadir et al., 2012; Kamarudin et al., 2022). Although their studies do not specifically examine green roofs, the possibility of similar accessibility challenges in such spaces needs further investigation.

While green infrastructure, including green roofs, contributes to sustainability, its implementation often overlooks social aspects such as accessibility (de Oliveira Santos et al., 2024). These challenges are worsened by maintenance priorities that focus on structure over inclusion (Ali Ariff et al., 2023). While MS 1184:2014 outlines important accessibility standards, its practical application is often neglected (Ahmad Zawawi et al., 2024). This raises the question of whether green roof designs have been considered or assessed for compliance with these requirements.

To ensure that green roofs incorporate reasonable adjustments (Frías-López & Queipo-de-Llano, 2020), inclusive features such as wider ramps, accessible routes, and appropriate signage are essential for enabling the disabled community, particularly wheelchair users and those with mobility difficulties, to enjoy the same benefits as others, including stress relief and engagement with nature, as highlighted by Sundara Rajoo et al. (2021). Moreover, Archer (2013) emphasized that built spaces are not neutral; they are socially constructed environments that reflect cultural values and shape human interactions. Incorporating accessibility into green roofs planning and design supports not only regulatory compliance but also the broader goals of disabled community towards social sustainability. Therefore, identifying physical barriers that hinder accessibility is crucial to ensuring inclusive use of the space.

2.4 Identifying Physical Barriers in Green Roofs

One of the effective ways to identify physical barriers in the built environment is by conducting an access audit. Holmes-Siedle (1996) highlighted that the purpose of an access audit is to identify and address accessibility issues within buildings that need to be rectified. Rahim and Abdullah (2009), Kadir and Jamaludin (2012), Hashim et al. (2012), and Kamarudin et al. (2015) are among the researchers who conducted an access audit to evaluate the compliance of their case studies with accessibility standards and to identify potential barriers that could impede access for the disabled community in the built environment of Malaysia. The access audit evaluates a variety of accessibility factors, such as ramps, door dimensions, signage, and layout, to ensure that the environment is accessible to all individuals, irrespective of their physical capabilities. In addition to assessing the accessibility of buildings, access audits are also implemented to assess the accessibility of the street-level environment and transportation. This ensures that pedestrian pathways, crossings, and public spaces are accessible to all users, including the disabled community (Ramli et al., 2022; Kamarudin et al., 2023).

Some existing studies have begun to address related issues, despite the fact that limited research has been conducted specifically on green roof accessibility. For example, Keirstead (2024) investigates the impact of accessible design on the health of roof vegetation and maintenance practices, while Ali Ariff et al. (2023) investigate the social potential of accessible green roofs in Malaysian public institutions, with a particular emphasis on safety and architecture. This highlights a significant gap in the literature, particularly concerning access audits that evaluate green roof accessibility. Addressing this gap will contribute to a more inclusive urban environment.

3.0 METHODOLOGY

This study adopted a qualitative approach by utilizing an access audit as the method for assessing the accessibility of the case study green roofs. This study concentrates on the accessibility of amenities located on the designated green roofs for wheelchair users and individuals with mobility impairments. This emphasis is justified by the fact that wheelchair users frequently encounter the most immediate and conspicuous challenges when navigating physical environments, including stairs, limited entrances, and uneven surfaces (Kamarudin et al., 2022).

3.1 Case Studies

The case studies were conducted at three locations in Shah Alam, Malaysia: Case Study 1 (CS1) and Case Study 2 (CS2), both located in Seksyen 13, and Case Study 3 (CS3), located in Subang Pelangi. Shah Alam was selected as a result of its accelerated urban expansion and the growing prevalence of green roofs in high-rise residential buildings. It offers a practical and pertinent environment for the investigation of accessibility concerns in the context of contemporary urban living, as a planned city with an emphasis on sustainable development. CS1 and CS2 each have a single green roof, whereas CS3 has two levels of green roofs, providing residents with additional outdoor spaces and amenities. Table 1 shows the summary of the building background, and Figure 1 illustrates the diagrammatic location of the green roof in the case study buildings.

Table 1. Summary of building background

Item	**CS1**	**CS2**	**CS3**
Location	Seksyen 13, Shah Alam	Seksyen 13, Shah Alam	Subang Pelangi
Year of occupied	2018	2018	2020
Number of stories	28	20	14
Location of green roof	Rooftop	Level 7	Level 3 & rooftop
List of facilities and amenities	Badminton hall, barbeque area, swimming pool & jacuzzi, gymnasium room, landscape garden, playground, sky lounge and reading room	Swimming pool & jacuzzi, gymnasium room, barbeque area, reflexology path, landscape garden, multi-purpose hall, playground, lounge, sauna and prayer room	*Level 3* Swimming, wading, spa pool & jacuzzi, gymnasium room, barbeque area, playground, sky lounge, *Roof top* Adult fitness stations, community garden and reflexology path

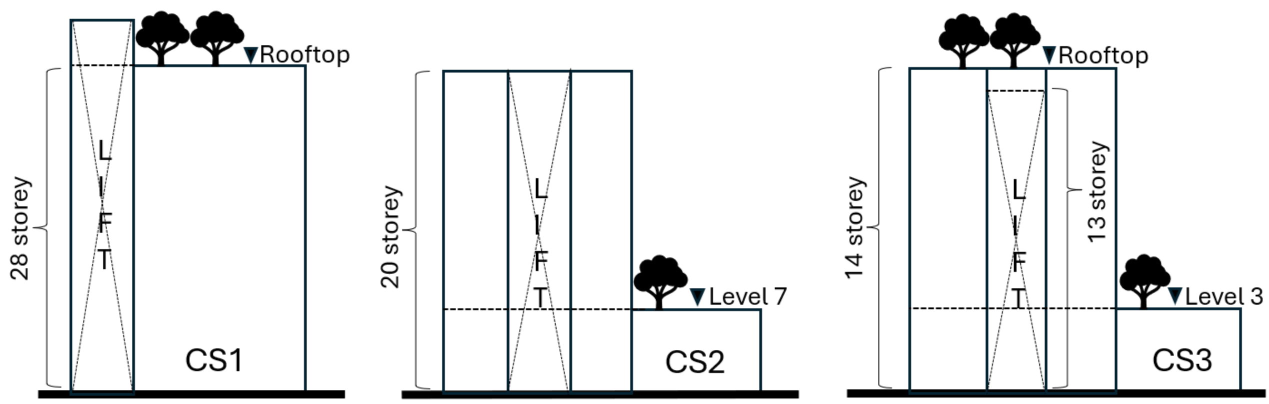

Figure 1. Diagrammatic green roof location at CS1, CS2 and CS3 (from left to right)

3.2 Data Collection through Access Audit

This study examines the accessibility of the selected green roofs, focusing on potential barriers that may restrict access for wheelchair users and those with mobility difficulties. The access audit follows the minimum requirements outlined in the MS 1184:2014 on universal design and accessibility in the built environment. Recent studies, such as Jaafar et al. (2023) and Ramli et al. (2022), highlight the continued relevance of access audits in assessing compliance within the built environment, building upon the foundational work of Holmes-Siedle (1996).

Ahmad Zawawi et al. (2024) highlight that access audits are already established in Malaysia and serve as a critical first step in identifying accessibility barriers across various building types. Their review referenced studies by Jaafar et al. (2023) on public hospitals, Hashim et al. (2020) on shopping malls, Abd Samad et al. (2019) on mosques, Hooi and Yaacob (2019) on heritage buildings, and Isa et al. (2016) on transport facilities. While gaining perspectives and experiences from disabled community is vital, this study begins with an access audit as a foundational step, given that no access audit has yet been conducted to assess the accessibility of green roofs in Malaysia.

To ensure a standardized and thorough assessment, an access audit checklist was developed using an AI-based tool, *Universal Design Assistant* (UD-AI), which strictly adheres to MS 1184:2014. UD-AI is a copyrighted tool developed by one of the research team to support accessibility assessments based on local standards (Kamarudin, 2024). It is a custom version of ChatGPT specifically designed to assist professionals such as architects, designers, planners, and auditors, and also for the built environment students in interpreting and applying the MS 1184:2014.

The access audit involved on-site evaluations of the case studies, assessing accessibility from arrival points to the green roof spaces. This included an audit of the parking facility, access routes, entrances, vertical transportation, and circulation within the green roof areas. As the assessment focused on accessibility requirements for those with mobility difficulties of both residents and visitors, it is necessary to initiate the audit from the parking facility.

4.0 FINDINGS AND DISCUSSION

This study has highlighted several key accessibility challenges potentially faced by wheelchair users and those with mobility difficulties when using green roofs in high-rise residential buildings in Shah Alam, Malaysia. The access audit revealed a range of barriers, including inadequate signage, steep ramps, and restricted access to elevators and key facilities. However, the study also provided valuable insights into how these spaces could be improved to foster greater inclusivity and contribute to the social sustainability of urban environments. Some recommendations for improving accessibility of the case studies are embedded within the relevant sections of the discussion, in accordance with the provisions of MS 1184:2014.

In line with the research conducted by Ali Ariff et al. (2023), which highlighted the social potential of accessible green roofs, this study supports the argument that green roofs have the potential to enhance social interaction and community engagement. However, as noted in the access audit, many green roofs fail to meet universal design standards, limiting their effectiveness as public spaces for the disabled community. Additionally, the findings align with the observations of Kamarudin et al. (2022), who pointed out that accessibility remains a critical social sustainability issue, as many built environments do not fully accommodate the disabled community.

4.1 Parking and Access Routes

The access audit revealed that while accessible parking is provided in all three case studies, the dimensions of these spaces are insufficient for larger vehicles like those equipped with hydraulic wheelchair lifts. According to the audit, the parking sizes range from 3200mm x 4800mm to 4500mm x 4900mm, which may be sufficient for standard vehicles but inadequate for longer vehicles like vans with hydraulic wheelchair lifts. To accommodate such vehicles, the recommended size for an accessible parking bay should be at least 3600mm x 5400mm. This dimension provides additional length compared to the minimum 4800 mm, accommodating larger or accessible vehicles such as vans.

Additionally, Figure 2 shows the absence of standing signage to clearly mark accessible parking spots increases confusion, making it harder for disabled drivers to locate designated areas. This highlights the need for clearer identification and appropriately sized parking spaces to meet the accessibility needs of all users.

Figure 2. Accessible parking space at CS1, CS2 and CS3 but lack standing signage (from left to right)

Kamarudin et al. (2023) similarly discussed the importance of clear facility and amenities design and navigability for the disabled community. Their study highlighted how poor facilities and a lack of clarity in transportation systems create significant barriers for wheelchair users in urban environments. This relates to the issues identified in the parking audit, where the lack of appropriate space dimensions and unclear signage mirrors the transportation challenges described by Kamarudin et al. (2023). Both situations underscore the importance of ensuring that facilities and infrastructure are designed in a way that provides ease of access, clarity, and usability for the disabled community.

4.2 Building Entrances

Manual doors in all three case studies pose significant challenges for the disabled community, particularly those with mobility difficulties, as they require considerable force to open. This limits independent use and increases reliance on assistance. Kadir and Jamaludin (2012) highlight the role of automatic doors in promoting independence by reducing physical effort, aligning with universal design principles that prioritize accessibility for all users.

Figure 3. Main entrances at CS1, CS2 and CS3 with security assistance (from left to right)

The access audit reveals that while the main entrances meet the minimum width requirement of 900mm, none of the case studies provide automatic doors. Although each case study offers some security assistance, this does not fully resolve the accessibility challenges posed by manual doors. MS 1184:2014 recommends installing automatic or power-assisted doors to enhance accessibility and support independent access.

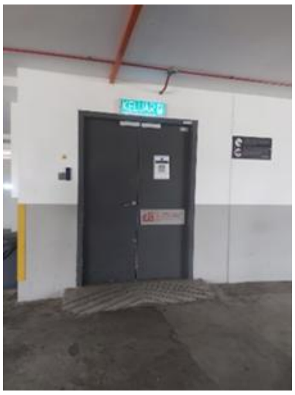

Figure 4. Steep ramp in front of entrance in multi-level parking in CS1

Figure 4 shows the entrance from the multi-level parking in CS1, which features a manual door with a lever. However, there is a steep ramp located directly in front of the door, which poses a challenge for wheelchair users, and no security personnel were observed to assist with access.

Rahman et al. (2023) stress the importance of accessible design in public spaces for enhancing inclusivity and user well-being. Making entrances more accessible is crucial for reducing the stress caused by physical barriers and enabling independent access for all. Incorporating automatic doors would address one of the key obstacles to creating truly inclusive environments, allowing wheelchair users to navigate these spaces with greater ease and comfort.

4.3 Lifts and Staircases

In the case of lifts, although they generally meet width and internal space requirements, the placement of emergency buttons in some instances exceeds the accessible height range, limiting usability for wheelchair users. According to the audit, while the lift door dimensions comply with the minimum width requirement of 900mm and the internal size of 1400mm x 1400mm, the emergency intercom button in CS2 is positioned at

1400mm, making it difficult for wheelchair users to reach. Kadir and Jamaludin (2012) raised similar concerns in their study, emphasizing that the improper placement of controls and emergency systems in public facilities often creates barriers to accessibility. Ensuring that these critical components are within an accessible height range (between 900mm and 1200mm from the floor) is vital for enhancing the usability and safety of lifts for the disabled community.

In contrast, CS3 provides a good example by including a separate panel designed specifically for wheelchair users and children, ensuring that the controls are easy to reach and improving accessibility for all users.

Figure 5. Vertical button panel for typical users (left); horizontal button panel for the lower-reach users (right)

The absence of lift access to rooftop areas, as observed in CS3, creates a major barrier to accessing recreation area at the green roof (Figure 6), requiring users to climb stairs. This reflects a broader issue highlighted in the study where vertical circulation frequently fails to meet MS 1184:2014, restricting access for mobility-challenged users. As noted, such inaccessibility not only limits physical access but also reinforces social exclusion, turning green roofs into spaces of inequality (Archer, 2013).

Figure 6. Inaccessible recreational area at the rooftop of CS3, where users need to climb stairs to reach to this level

This issue is crucial because vertical accessibility is key to ensuring that all users, regardless of mobility, can access these spaces. Mesimäki et al. (2019) also underscored the importance of accessibility in green spaces, including rooftops, emphasizing that limitations in vertical transportation can severely restrict the inclusivity of such areas. It is suggested that to foster inclusivity in public spaces like green roofs, special attention should be given to ensuring vertical access to all floors, including rooftops, where accessibility remains a major concern.

4.4 Green Roofs Space

The findings from auditing the green roof space underscore significant challenges in meeting the standards outlined in MS 1184:2014. Several key areas, such as ramps, pathways, seating, barbecue areas, toilet facilities, and additional communal features like swimming pools and prayer rooms, demonstrate barriers that prevent full access for the disabled community. Addressing these issues is critical not only for legal compliance but also for ensuring that green roofs can function as inclusive, accessible spaces that contribute to the overall well-being and social cohesion of the community.

4.4.1 Ramps, Pathways, and Signage

All pathway widths exceed the minimum requirement. However, none of the case studies meet the MS 1184:2014 standard of a 1:12 gradient for ramps, creating a significant challenge for wheelchair users. In CS1, the audit reveals that the ramp in front of the lift leading to the green roof space has a gradient ratio of 1:8, which exceeds the allowable gradient, making it steeper than recommended. Similarly, in CS2, a 1:6 gradient ramp is used, and despite its textured surface designed to prevent slipping, the steepness remains problematic for wheelchair users. CS3 also features a ramp with a gradient of 1:9, further limiting accessibility to certain areas. One of the best ramp examples in CS1 is the L-shaped ramp in front of the toilet, with a gradient ratio ranging from 1:9, 1:8, to 1:10 as shown in Figure 7.

In addition to the non-compliant ramps, uneven surfaces, such as pebbled pathways in CS2, present impaired accessibility issues for wheelchair users. The pebbled pathways may serve aesthetic purposes but compromise usability; a concern echoed by Mesimäki et al. (2019) and Rahman et al. (2023), who stress the need for designs that balance well-being and functionality. Pathways should ideally be smooth and stable to provide easier movement for wheelchair users and those using mobility aids. Moreover, while signage was present at all the case studies, it lacked clear directional indicators, making navigation challenging for users unfamiliar with the space.

Figure 7. L-shaped ramp in CS1; pebbled pathways in CS2; signage provided at the toilet facility without directional indicators in CS3 (from left to right)

4.4.2 Seating and Barbecue Areas

The analysis of seating areas and the barbecue facility across the three case studies reveals several accessibility challenges. In CS1, seating areas are inaccessible due to wooden decks lacking ramps, preventing wheelchair users from accessing these spaces. CS2 presents impractical seating arrangements, with tables and benches too high for wheelchair users and even uncomfortable for non-disabled individuals. CS3, while providing accessible seating on Level 3, still has issues with the barbecue facility.

Figure 8. Wooden decking lacks of ramp in CS1; impractical bench and table height in CS2; insufficient knee clearance for the hand basin, and the faucet handle is beyond reach in CS3 (from left to right)

In all case studies, while the barbecue areas comply with standard hand basin height, none provide adequate knee space, limiting usability for wheelchair users. CS1 lacks knee clearance entirely, while CS2 and CS3 have additional issues such as unreachable faucet handles and, in CS2, a shallow, uncovered drain that further complicates access. These inconsistencies dilute the potential of green roofs as shared social spaces and mirror what Frías-López & Queipo-de-Llano (2020) call a lack of 'reasonable adjustments' in public design.

These findings suggest that while there is some adherence to accessibility standards, the designs fail to meet the functional needs of wheelchair users. Adding adequate knee clearance, ensuring faucet handles are within reach, and addressing seating height would make these communal spaces more inclusive, supporting compliance with MS 1184:2014.

4.4.3 Toilet Facilities

The accessibility of the toilet facility varies across the case studies. In CS1 and CS3, while the physical dimensions of the toilets meet accessibility requirements, the absence of emergency intercom systems compromises user safety. Kadir and Jamaludin (2012) raised a similar concern in their audit of public buildings, where they emphasized the importance of including communication systems in accessible toilets to ensure safety and independence of the disabled community.

Additionally, the accessible toilets in CS2 are frequently locked, rendering them inaccessible when needed. This mirrors the issues raised by Kamarudin et al. (2022), who highlighted the inconsistent availability of accessible facilities in public spaces, noting that even when an accessible facility is present, it is often rendered unusable due to poor maintenance or operational practices. These issues suggest that, beyond meeting the basic design requirements, the operational aspects of accessibility must also be addressed to ensure that facilities and amenities are genuinely available and safe for all users.

4.4.4 Additional Amenities

The accessibility of amenities such as swimming pools, saunas, and prayer rooms varies across the case studies. In CS3, the absence of ramps prevents access to the swimming pool, which excludes wheelchair users from recreational spaces. This aligns with the findings of Rahman et al. (2023), who emphasize that accessible design of green roofs is essential for enhancing inclusivity and well-being for all users. Additionally, both CS1 and CS2 present barriers to sauna access due to high curbs and narrow doorways, while in CS3, the water tap in the ablution area is difficult to reach.

Figure 9. Steps at the swimming pool area in CS3; inaccessible sauna entrance in CS2; inaccessible water taps in the ablution area in CS3 (from left to right)

All of the access audit findings demonstrate the need for more inclusive design approaches that address access to all communal and recreational spaces, ensuring they meet accessibility standards and foster inclusivity. As Rahman et al. (2023) and Mesimäki et al. (2019) noted, green roofs play a vital role in fostering social interaction, relaxation, and mental well-being. However, if these spaces remain inaccessible to the disabled community, their potential to contribute to social sustainability is diminished. Ensuring that all residents, regardless of their physical abilities, can enjoy these spaces is crucial for promoting inclusivity and community engagement. The inclusion of features such as ramps, wider pathways, and accessible signage would help in realizing the social benefits that green roofs offer, including stress reduction, relaxation, and engagement with nature (Rahman et al., 2023).

Table 2 presents a summary of the access audit findings, outlining key accessibility barriers identified throughout the case study, from the parking facility to circulation routes leading to the amenities located within the green roof spaces.

Table 2. Summary of access audit findings

Elements	**CS1**	**CS2**	**CS3**
Parking and access routes	Accessible, flat, stable, and non-slip, with a disabled symbol marked on the floor; not suitable for larger vehicles; no standing signage.	Accessible, flat, stable, and non-slip, with a disabled symbol marked on the floor; not suitable for larger vehicles; no standing signage.	Accessible, flat, stable, and non-slip, with a disabled symbol marked on the floor; not suitable for larger vehicles; no standing signage.
Building main entrances	Ramp is quite steep, but security is available if assistance needed; the manual door with reachable door handle.	Compliant ramp but lacks automatic doors; manual door with reachable door handle.	A gently sloping ramp connects the tarmac to the corridor; no split level at the main entrance; lacks automatic doors; manual door with a reachable door handle.
Lifts and staircases	Compliant lifts; staircases limit access to some areas (e.g., swimming pool); staircase/steps with a non-slip surface.	Compliant lifts, but the highest button is a bit high for wheelchair users; staircase/steps with a non-slip surface.	Compliant lifts, but the lifts do not reach the rooftop; staircases restrict access to the community garden; staircase/steps with a non-slip surface.
Green roof spaces	Wide pathways but lacks ramps to key areas (e.g., swimming pool); clear signage.	Wide pathways but pebbled surfaces hinder wheelchair use; signage with arrows is provided at the green roof lift lobby.	Inaccessible rooftop due to stairs; facilities signage at the swimming pool area (level 3) is only provided in front of each facility.
Ramps	Various ramps with different gradients in different areas, some are too steep (1:6).	Ramp gradient steeper than recommended (1:9).	No ramp is provided in the swimming pool area.
Seating	Some seating areas are inaccessible due to wooden decks without ramps.	Table and bench heights are impractical even for non-disabled users.	Accessible seating area at level 3.
Toilet	Compliant disabled toilets; no emergency intercom.	Disabled toilets locked; door size complies.	Compliant disabled toilets; no emergency intercom.
Barbeque area	Compliant hand basin height but without knee space.	Compliant hand basin height but insufficient knee space; uncovered shallow drain in front of hand basin; faucet handle out of reach for wheelchair users.	Compliant hand basin height but insufficient knee space; faucet handle out of reach for wheelchair users.
Additional facilities	Inaccessible changing room and sauna due to narrow doorways.	Inaccessible changing room and sauna due to narrow doorways; inaccessible female prayer room due to stairs; level difference for access to the men's prayer room, but no ramp available.	The prayer room is difficult to access due to narrow doorways; curbs obstructing the ablution areas.

5.0 CONCLUSION AND FUTURE DIRECTION

Research specifically addressing the accessibility of green roofs remains scarce, with little to no studies found that directly assess these spaces using access audits. This access audit highlights the need for more inclusive design in green roofs, focusing on improvements in ramp gradients, signage, and access to essential facilities. Addressing these issues will enhance both accessibility and usability, making green roofs more inclusive and supportive of social sustainability. By removing physical barriers, these spaces can promote equity in urban environments, allowing everyone to engage in recreational and social activities. Improving accessibility can also help reduce social isolation for the disabled community, offering equal opportunities for engagement within communal spaces.

This study makes several original contributions to the field of accessibility. It represents the first formal access audit of green roofs in high-rise residential buildings in Malaysia, addressing a notable gap in existing literature. The study highlights unique access barriers in elevated communal spaces that are often overlooked. The use of the UD-AI in generating the access audit checklist introduces a novel AI-assisted approach to conducting audits in alignment with MS 1184:2014. Additionally, by framing accessibility through spatial theory, the study broadens the discourse from purely technical assessments to include the social implications of exclusion in the built environment. These findings contribute valuable insights for facility managers, designers, and policymakers aiming to promote more inclusive green roofs in urban residential developments.

Despite some accessible features, significant barriers remain, including steep ramps, inadequate signage, and locked or inaccessible communal facilities. Inaccessible green roofs may unintentionally signal that certain groups are not expected to use or belong in these areas. When green roofs are not accessible to wheelchair users, it can lead to both physical exclusion and a sense of being socially left out. This highlights the need for inclusive design that not only meets technical standards but also supports equal participation in shared urban spaces. Better design and maintenance of these spaces are crucial to ensuring that all users, including the disabled community, can benefit from green roofs. Addressing these shortcomings will contribute to a more inclusive and sustainable urban landscape.

To enhance accessibility in line with MS 1184:2014, green roofs in high-rise residential buildings should include parking bays measuring at least 3600 mm x 5400 mm with clear vertical signage. Entrances should be fitted with automatic doors, and ramps must not exceed a 1:12 gradient. Lift emergency buttons should be positioned between 900–1200 mm, and lift access must reach all levels. Pathways should be smooth and slip-resistant, while signage must be clear and at accessible heights. Communal areas must provide adequate knee clearance and reachable fixtures, and accessible toilets should include emergency intercoms and remain unlocked. Ramps and widened doorways are also essential for accessing all amenities. These improvements ensure compliance and promote inclusive use of green roofs.

As architecture plays a powerful role in either fostering inclusion or reinforcing exclusion, green roof design extends beyond technical considerations, carrying implications for equity and user experience, including for the disabled community. Hence, future research can incorporate alternative methods, such as the go-along interview method, to gain first-hand insights from the disabled community as they navigate barriers in the built environment. This approach would provide a deeper understanding of their experiences and challenges, contributing to more inclusive design solutions. Additionally, future research is recommended to explore accessibility issues faced by other disability categories, other than those with mobility difficulties. This will help ensure that green roofs and similar urban spaces are designed to accommodate diverse needs.

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