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Environmental Design for Urban Cooling, Access, and Safety: A Novel Approach to Auditing Outdoor Areas in Residential Aged Care Facilities

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Abstract: Strategies and guidelines for best practice environmental design typically have a singular focus and intended outcome, for example, green infrastructure management for urban cooling in a hotter climate. However, when applied to specific situations such as aged care, matters such as accessibility, wayfinding, and safety are also critical. Combining various audit tools offer multiple benefits to meet a variety of needs for thermal comfort, health, and well-being, as well as cost-effectiveness. In the absence of such a tool, using a place-based analysis, we developed a novel audit tool for external settings of residential aged care facilities (ACFs) incorporating urban cooling, Crime Prevention Through Environmental Design (CPTED), and universal design criteria. To determine how ACFs perform in the face of increased levels of urban heat required evaluation of additional urban cooling measures. The Audit Tool was developed and tested in collaboration with ACFs across sub-tropical and tropical areas of Australia, varying in climate, scale, and urban density. Quality of life for residents, visitors, and staff of ACFs can be supported by the provision of green infrastructure to improve the thermal comfort of outdoor settings and, if located appropriately, reduce the need for an increase in internal air-conditioning. The aim of this article is to propose a user-friendly Hybrid Environmental Design Audit Tool (HEDAT) to support facility managers, planners, and design consultants to inform the prioritization and targeting of interventions and monitoring of implementation and outcomes.

Keywords: aged care; Crime Prevention through Environmental Design; universal design; green infrastructure; accessibility; shading; evaporative cooling; urban design; landscape architecture; site evaluation

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1. Introduction

Climate change is leading to increased heat: more days with high temperatures [1] and more frequent heatwaves of longer duration [2]. Even if we reach net zero emissions [3,4] average temperatures will have increased, leading to more severe impacts, for example, on urban populations due to the urban heat island effect (UHIE) [5–7]. Adapting our urban communities to climate change impacts requires understanding the risks and how the local environment can support mitigating urban heat island effects and increase resilience through awareness, investigation of options, and preparedness actions—that is, through adaptation planning [8–10]. Identifying which vulnerable communities are affected disproportionately is an initial step in the adaptation planning process. While infants, people with disabilities, or certain illnesses of all ages, are considered particularly vulnerable to heat stress, our research context is residential care facilities for older people. Older people are at greater risk when exposed to both hot and cold extreme weather [11] due to kidney disease, diabetes, and heart disease (decreased cardiac output, reduced plasma volume, and ability to sweat due to medications) [12–14]. By 2050, there will be more people aged 60 years and older than children younger than five years [15]. This article thus proposes an audit tool (used as part of a Heat Adaptation Planning process) to improve cooling, access, and security for older people.

Increasing heat is compounded in urban areas due to the UHIE resulting from urban morphology and spatial pattern [6,7], hardened surfaces [16] and energy usage [17,18]. As a countermeasure, open windows and doors provide ventilation to support thermal comfort [19] and reduce airborne transmission of disease [20]. Understanding climatic trends—temperature and humidity—is, therefore, a fundamental requirement. Vegetation contributes to cooling by keeping the air cool, moist, and fresh [21–23] and enhances thermal comfort when close to living areas. With its origins tied to climate change adaptation, Nature-Based Solutions (NBS) [24]—including green infrastructure provisions, offer interventions using vegetation as an adaptation option. While there are many definitions that vary based on their spatial and temporal applications [25] we operationalize the term Green Infrastructure (GI) to mean "all-natural, semi-natural and artificial networks of multifunctional ecological systems within around and between urban areas, at all spatial scales" [26] (p. 169) managed to provide a range of ecological, social, and economic benefits [27] (p. 155). Green infrastructure can occur in the public or private realm—for example, planting street trees along public roads and alleys; public parks, community gardens, and urban wetlands; permeable vegetated surfaces; private and institutional plantings, green roofs or walls of private and public buildings [28].

Green Infrastructure supports multiple ecosystem services and benefits [29–32] such as enhancing visual amenities, noise reduction, stormwater runoff control [33], energy efficiency [17,18], supporting public health and well-being [34–36], achieving cooling [19,37] and enhancing biodiversity [38]. GI offers urban residents (whether during a heat wave or not) manifest benefits through the cooling effects of vegetation—in conjunction with other materials—providing shade, reducing heat emissions [16,17], supporting evaporative cooling [30,39], and realizing cost savings in health care and energy consumption for cooling [17–19,40]. Greenspaces are also known to provide stress relief and restoration in general [41,42]; GI has a clear role in mitigating and mediating "anthropogenic climate change and declining human health" [43]. Recent reviews of the literature concerning GI report multiple definitions, functions, benefits, drivers, barriers, and challenges to its implementation.

Studies of what older people want in their homes and neighborhoods confirm that they value and benefit from greenspace, gardens, and shade but also have concerns about accessibility to enhance inclusion and physical safety, being secure from crime, and consequent physical injury [34,44]. Less is known about how environmental design, including the range of GI options and selection of materials, supports older residents in urban communities, including not only by urban cooling but also by interacting in greenspace through access, inclusion, and safety features [45].

Since approximately 17% of Australians over 80 years of age reside in aged care facilities (ACFs) [46], this is an appropriate starting point for the investigation of ways to mitigate heat and improve amenities for older people through GI. Providers of ACFs in Australia are under increasing pressure to do more with less in servicing the needs of elderly citizens and their families [45]. Understanding the important role of the external environment in supporting urban cooling, as well as accessibility, and safety, is critical: for facility managers in marshaling and allocating resources; and for built environment design professionals tasked with planning and designing refurbishment and establishment of new facilities. Davies and Lafortezza [47] suggest that infrastructure providers—public or private—are in a pivotal position to deliver the offerings of NBS as climate-sensitive interventions. Aged care facility providers need strategies for GI provision that can be used as a guide for investment, deliver on values/missions, build in a range of benefits, and weigh up the costs and benefits of provision. The first step in adaptation planning is understanding the existing situation to establish a baseline from which to monitor change [10,27]. Undertaking an environmental audit facilitates assessing both the existing and the potential for GI to weigh up options and determine priorities for GI provision based on criteria such as contribution to heat reduction, cost, and visual amenity. It contributes to improving our understanding of thermal comfort and environmental quality [48,49] and adaptation planning by enabling monitoring, evaluation, demonstration of achievements, and adaptation over time, as necessary [10,45].

This article reports on research addressing the complexity of environmental design for older people, given their accessibility and safety need, and to avoid unintended consequences, through a Hybrid Environmental Design Audit Tool (HEDAT). In the absence of an existing audit tool fit suited to assessing green infrastructure/environmental design with Crime Prevention through Environmental Design (CPTED) and Universal Design (UD,) including accessibility, using a place-based analysis, we developed and applied the novel HEDAT in partnership with two ACFs in subtropical Australia. We analyze how existing GI provision at a site level supports urban cooling, access, inclusion, and personal and physical safety and identify the potential for GI provision and maintenance, to support urban cooling, accessibility, and safety. It is part of a larger multiple-methods study that aimed to test and validate the approach and feasibility of ACF heat adaptation planning [9]. The larger study, to be reported separately, drew on additional site-level data collected to measure thermal comfort—using weather sensor equipment—and included participatory methods of identifying the ACF community needs and garnering feedback on design options. It also refined the HEDAT as a result of testing its applicability in other climatic and urban density situations. Importantly, the aim of this article is to propose a novel HEDAT that contributes to knowledge, practice, and policy concerning climate change adaptation planning. Supporting infrastructure providers with a better understanding of appropriate GI options and additional features should facilitate uptake in heat adaptation planning by the private and public sectors. Furthermore, it supports providing green infrastructure as an NBS at different spatial scales: in public streetscapes and parks and in private residential complexes and institutional settings. Before we describe our case study sites (Section 3), report our results (Section 4), and discuss what they mean (Section 5), section two describes the environmental design criteria that informed the development of our novel HEDAT and how it can be applied to collect and analyze site data.

2. Materials and Methods

2.1. Environmental Design Criteria for a Novel Audit Tool

The audit assesses GI, typically in the form of lawns, gardens, shrubs, and trees or other structures providing shade and airflow to provide comfortable resting and gathering points and along pathways to encourage use. An audit tool specifies criteria used to compare or measure processes and/or features of an entity, frequently administered by an independent third party. Following a review of existing audit and evaluation tools concerning greenspace management [50], GI incorporating stormwater management [51,52], urban blue spaces [53–55] and green infrastructure plans [56,57], we determined a novel tool was needed for auditing the environmental design of outdoor areas in residential aged care facilities to determine priorities for improvement. To develop our audit tool, we drew on three complementary but well-documented environmental design approaches: Urban Cooling Strategies [19], UD [58], and CPTED [59–61] (see Figure 1).

Urban cooling strategies [19] including existing horizontal and vertical surfaces, vegetation types and location, evaporative cooling features, and provision of shade, frame the audit, which also incorporates criteria each for UD [58], and CPTED [59].

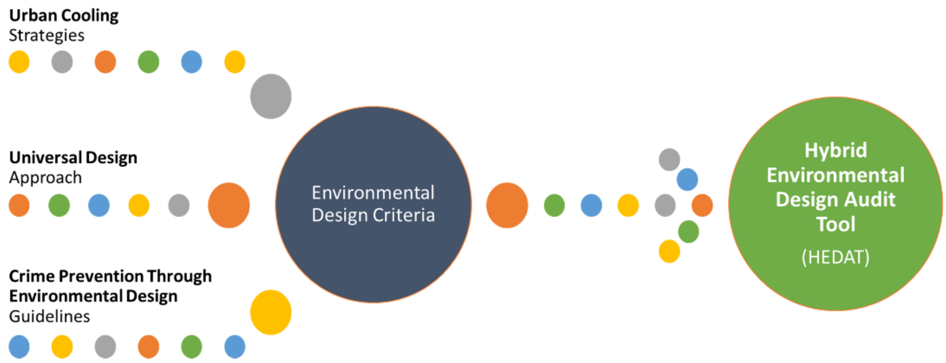

Figure 1. Process used to (1) identify relevant environmental design criteria and (2) develop the HEDAT using well-documented environmental design approaches: Urban Cooling Strategies [19]; UD [57]; and CPTED [58–60] (Image Source: Authors).

2.1.1. Urban Cooling Strategies

Based on the Guide to Urban Cooling Strategies [19] the first four criteria of the HEDAT reflect urban cooling measures. Regarding horizontal and vertical surfaces, the relationship between built form and the reflection of radiation—dependent on materials' properties—has implications on the resulting amount of heat absorption in specific spaces. When the sun reaches a built element, only part of its energy is reflected, with the remainder contributing to the increase in surface temperatures [62]. This is also what makes the provision of shade so important: to reduce the amount of solar radiation reaching surfaces and contributing to heat absorption. Shade can be provided by built elements and vegetation, and in the case of vegetation, its type and location matter. The size, quantity, and layout of urban greenery and the physiological characteristics and spatial arrangement of urban vegetation significantly influence their cooling effect [28,62]. In addition, vegetation form—particularly trees—determines the direction and shape of shadows, as well as how much solar radiation and air circulation will go through it. Evaporative cooling is the process of cooling the air by evaporating water, and elements that increase relative humidity can reduce air temperatures in dry weather conditions (e.g., vegetation and water features) [37].

2.1.2. Universal Design Principles

Universal Design involves the design and composition of an environment so that it can be accessed, understood, and used to the greatest extent possible by all people regardless of their age, size, or ability [58]. Among other things, it aims to:

- minimize hazards and accidents;
- ensure legibility through visual, sound, or tactile means, which is especially important for those with sensory limitations;
- ensure efficient, safe, and comfortable use of the built environment by a range of body sizes and shapes, as well as accommodating the use of assistive devices and personal assistants.

In Australia, new buildings and major renovations must comply with AS 1428—Design for Access and Mobility [63–68]. In addition, many local governments prescribe guidelines for open space and vegetation planning and design. In general, public footpaths are now being designed to a minimum 2.1 m width—the minimum width that would allow for a person with an assistive device (such as a walking frame) to walk beside another person. Principles for enabling environments for people with dementia have also informed the audit tool [69]. These include features of therapeutic value; orientation/legibility; enabling interaction with friends, family, pets, and caregivers; and meaningful activity.

While many of these criteria are accepted features for access to and within ACF buildings (such as access ramps and hobless showers), there is no legal requirement, and therefore frequently less consideration is given to outdoor areas. Safe, even-graded walking paths, for example, are essential—paths of travel or resting areas that are hazardous or uncomfortable or do not allow socializing will inhibit use [70]. Raised garden beds can attract keen gardeners and carers, facilitate meaningful activity, and stimulate the senses to support age-friendly and inclusive places [71]. Shade structures at resting and gathering points and along pathways are crucial for access and mobility. In this case, we draw on UD principles as guidance to inform our fifth criterion [58].

2.1.3. Crime Prevention through Environmental Design Guidelines

Being able to clearly see residents in outdoor areas for safety reasons prompted the addition of features of CPTED [59,61,72]. Aspects of CPTED that are particularly relevant to ACFs include: being able to observe people through a clear line of sight and strategic lighting (surveillance); encouraging the use of areas (activation); clearly defined boundaries between private, semi-private, community-group space, and public (e.g., individual patios; fencing the exterior—territoriality); and legibility or wayfinding [72]. Appropriate wayfinding in an ACF includes assisting people in knowing where they are; how to find their room, common areas, nursing staff, or reception; and how to find an exit (particularly important in an emergency). Appropriate wayfinding can reduce the burden on staff and ease the stress on residents who may become confused; positive perceptions of safety result in increased physical activity levels of the elderly [35]. Greenery, which calms people, combined with wayfinding features, can reduce emotional stress [42]. Themes of public health and sustainability are now recognized as being integral to crime prevention theory (Third-Generation CPTED) in supporting quality of life [60]. CPTED measures were incorporated into the fifth criterion.

2.1.4. Hybrid Environmental Design Audit Tool

A combined GI and UD audit toolkit was initially proposed to ensure that GI interventions such as tree planting do not have unintended negative consequences for seniors, such as becoming trip hazards, and in fact, can facilitate their health and well-being through shade and amenities. Recognizing seniors' concern for safety, we also drew on CPTED principles such as surveillance and legibility. The innovative HEDAT (refer to Supplementary Material) thus uses qualitative measures adapted from design approaches to Urban Cooling, UD, and CPTED (see Table 1). These may be adapted to local conditions, requirements, and guidelines. Each of these was developed for a specific purpose and is well-regarded for their intended use. However, we suggest their integrated application delivers a more holistic and suitable approach that offers multiple benefits of identifying opportunities to improve the environmental design from varied perspectives, including urban cooling, safety, and universal access.

Table 1. Environmental Design criteria sources and their relationship to the HEDAT criteria and measures.

Source	HEDAT Criteria	HEDAT Measures
Urban Cooling Strategies [19]		
	1. Surfaces—Horizontal & Vertical	
	1.1 Surfaces provide high solar reflectance	1.1 (a) Pavements comprise lighter pigments to increase albedo (the proportion of the incident light or radiation that is reflected by the pavements/horizontal surface/s)
		1.1 (b) Walls, fences, gates, trellis & screens comprise lighter pigments to increase albedo (the proportion of the incident light or radiation that is reflected by the walls/vertical surface/s)

Table 1. *Cont.*

Source	HEDAT Criteria	HEDAT Measures
	1.2 Surfaces utilize materials to increase permeability and reduce heat	1.2 (a) Pavements utilize at least one of the listed methods/materials to improve permeability: ○ foam-based concrete ○ gravel with/without resin/binder (instead of cement) ○ permeable asphalt ○ concrete/grass pavers ○ vegetation in gaps ○ permeable sub-grade
	1.3 Pavements are shaded to reduce heat emission	1.3 (a) Pavements have vegetation planted in gaps as part of the design
		1.3 (b) Bioswales, rain gardens, planted areas, and/or lawns are present alongside pavements to improve permeability
		1.3 (c) Pavements are shaded
		1.3 (d) Walls, fences, gates, trellis & screens are shaded
	2. Vegetation	
	2.1 Vegetation is provided in a range of forms	2.1 (a) Existing GI comprises a combination of the following: ○ bioswales &/or rain gardens ○ gardens ○ trees ○ lawn areas ○ raised garden beds &/or planter boxes and/or containers (e.g., pots)
		2.1 (b) Existing GI provides for biodiversity through: ○ Species diversity ○ Species suited to aspect (exposure to wind and sunlight) and soil type ○ Connectivity to vegetation corridors that are internal and/or external to the site
		2.1 (c) Trees are formatively pruned to allow air circulation beneath the canopy
	2.2 Vegetation is provided in a manner that is cost-effective to maintain.	2.2 (a) Existing GI requires minimal maintenance (frequency and duration) such as mowing, pruning, aerial inspection, irrigation, edging, and weed control: ○ Deciduous trees (that shed a lot of leaves during autumn) are not too close to pathways to cause a slip hazard ○ Tree heights do not impair access, allow for walking under the canopy/s with ease, and avoid interference with powerlines ○ Gardens are adequately mulched and planted with no bare patches ○ Grassed areas are irrigated, mowed, edged & weed-free

Table 1. *Cont.*

Source	HEDAT Criteria	HEDAT Measures
		2.2 (b) Tree species are climate change resilient: ○ Drought tolerance ○ Strength of trees and branches during high winds and storms to limit the risk of falling trees ○ Deep roots that will not up-root pathways and cause trip hazards
	2.3 Green roofs and/or green walls are provided.	2.3 (a) Green roof and/or green wall are present
		2.3 (b) The green roof and/or green wall are healthy and well maintained.
	2.4 Opportunities for new green roofs and/or green walls exist	2.4 (a) Opportunities exist for green roofs (note any roofs with a low slope)
		2.4 (b) Opportunities exist for green walls
	3. Evaporative Cooling Methods	
	3.1 Evaporative cooling system methods are present	3.1 (a) Utilizes evaporative cooling system methods: ○ Misting fans ○ Fountains/ponds/water features with running water ○ Irrigation systems
	4. Shading Structures	
	4.1 Shading structures are provided	4.1 (a) The species of trees provide year-round shade
		4.1 (b) Trees provide horizontal and vertical surfaces with a shade much of the day
	4.2 Opportunities exist for increasing shade to exposed surfaces	4.2 (a) Exposed surfaces can be shaded through new works: ○ Installing additional/new shade structures ○ Planting trees ○ Installing new pavements in closer proximity to existing shading structures and/or trees
	4.3 Existing shaded areas are utilized	4.3 (a) Shaded areas used for resident activities and/or other purposes to mitigate urban heat on users, including for: ○ Pathways for walking/strolling ○ Seated areas ○ Observation of nature (e.g., birds, bees, fish) ○ Individual activities (e.g., reading) ○ Small Group activities (e.g., meetings, conversation with others, crafts & hobbies) ○ Formal/structured activities ○ Informal/unstructured use ○ Staff areas ○ Adjacent windows for views from internal areas

Table 1. *Cont.*

Source	HEDAT Criteria	HEDAT Measures
	5. Universal Design [58] **& CPTED** [72]	
UD Principle 1 Equitable use UD Principle 2 Flexibility in use UD Principle 6 Low physical effort UD Principle 7 Size & space for approach & use		5.1 Equitable & Flexible Approach & Use Relevant to a wide group of users, individuals, their preferences, and their abilities, regardless of size, used with ease. ○ Pathways, walls, fences, gates, trellis & screens ○ Gardens, lawns, planters, & pots ○ Water Features ○ Shading structures
UD Principle 3 Simple & intuitive use UD Principle 4 Perceptible information CPTED Principle 2 Legibility		5.2 Simple, Intuitive & Perceptive Design & communication—easy to be understood regardless of the range of abilities ○ Pathway system, walls/fences/gates for access management ○ Signs, pavement markers, and landmarks support wayfinding ○ Seats & shaded areas
UD Principle 5 Tolerance for error CPTED Principle 6 Vulnerability		5.3 Tolerance for Error Design minimizes hazards & reduces the risk to personal safety ○ Pathways, walls, fences, gates, trellis & screens ○ Gardens, lawns, planters, & pots ○ Water features ○ Shading structures
CPTED Principle 1 Surveillance		5.4 Design supports casual surveillance ○ Design facilitates unimpeded sightlines to key places ○ Avoids blind spots ○ Acknowledges differences in night and day usage, attitudes, accessibility, and capacities for surveillance
CPTED Principle 3 Territoriality CPTED Principle 4 Ownership of the Outcomes		5.5 Territoriality & Ownership of Outcomes ○ Users can determine and understand theirs and others' territory through clear delineations of public domain and private territory ○ Users can care about their shared settings, can see what is going on, and can respond in ways that will enhance their safety and the safety of others
CPTED Principle 5 Management		5.6 Management ○ Places are designed to minimize damage and the need for undue maintenance ○ Regular and reactive maintenance is implemented

2.2. Data Collection

Each ACF site was divided into multiple, relatively proportional-sized sectors that represented a common directional aspect for consistent growing conditions and ease of reference. Our process included taking site photographs using an Infrared/Thermal

Camera (FLIR C3), as well as with an iPhone (6) as a backup source for later reference if/as needed. Field notes recording the observed plant species were also prepared, with supporting photos. A Plant List was prepared to determine species diversity across each site and compare it to locally recommended plant species expected to be resilient in times of heat stress.

In the first instance, site photos and field notes were examined sector-by-sector as a desktop review to assign a preliminary score for each criterion with comments provided for use in the HEDAT. A score from 1–7 was assigned for each criterion in each sector, with each corresponding to a qualitative term (1—Very poor; 2—Poor; 3—Fair; 4—Good; 5—Very good; 6—Excellent; 7—Exceptional). Next, an on-site assessment using the HEDAT for each sector was undertaken during a follow-up site visit. Scores for each sector were adjusted based on site observations, finalized, and tallied for each sector. Each of the site visits involved the landscape architect on the research team, as well as another researcher, to test the ease of HEDAT use and corroboration on assessment.

2.3. Data Analysis

Triangulating photos, field notes, and observations of environmental conditions and attributes in each sector during each season, the HEDAT provides a list of issues. These concern key activity areas, pathways, seating areas, and lawns to identify and confirm—using thermal images—likely heat sources. Thermal camera images are useful to draw attention to tangible items of infrastructure (green and otherwise) that hold and radiate heat and, therefore, may be priorities for modification. The procedure reveals low-scoring items for the highest prioritization of mitigation actions and additional risk assessment as appropriate. Overall sector scores, as well as overall site scores, were derived for the four urban cooling criteria: (1) horizontal and vertical surfaces; (2) vegetation; (3) evaporative cooling; and (4) shading structures, as well as the fifth referring to UD and CPTED. Tallying scores for each sector, the results demonstrate the overall worst and best-performing sectors against each of the five criteria. Those settings performing poorly against specific criteria in the HEDAT identify opportunities for improvement and offer suggestions for a new design brief to inform the preparation of a landscape concept plan for each sector.

3. Case Study Sites

To evaluate localized environmental differences at the site level, we used two residential ACFs as case studies within Australia's humid, subtropical Sunshine Coast Regional Council: approximately 22 km apart, in the suburbs of Bli Bli and Caloundra (Figure 2). Mean temperatures range from 15.9 °C to 25.5 °C annually, with an average precipitation of 1483 mm [73]. Australia's Bureau of Meteorology predicts with high reliability that for Australia, temperatures will rise by +2.1 °C to +2.8 °C, and rainfall events will be more intense by 2040 with climate change [74].

Our HEDAT results demonstrate that the existing external environments of these ACFs include GI, typically in the form of lawns, gardens, and trees. However, while GI enhances visual amenities and supports passive recreation, our HEDAT results reveal limitations in its effectiveness in achieving urban cooling, enhancing biodiversity, and/or supporting perceptions of personal safety. Further, while some shading structures and pathways for access and mobility existed, GI maintenance and enhancement have been limited. We present the results commencing with a description of our case study area, followed by the specific outcomes revealed for each case study site.

The ACF case study sites were selected mostly because of the conditions concerning the aged urban resident population, growth, and vulnerability to heat stress in this location. The Sunshine Coast is one of Queensland's local government areas most vulnerable to UHIE [75] and the number of people over the age of 65 on the Sunshine Coast is predicted to almost double over a 20-year period (2021–2041) from 72,751 to 133,621 [76]. The proportion of people aged 60 years and over is already 6.6% higher than the rest of South East Queensland [77] and the two case study facilities are managed by a single not-forprofit organization that partnered on the study. The facilities are also adjacent to an identified urban development activity 'hot spot': a corridor from the large urban centers Maroochydore and Caloundra and adjacent smaller settlements [78]. Facility managers, medical staff, and groundskeeping personnel were committed to and enthusiastic about being involved and assisted the research team with access and data collection. Building upon our initial findings from our two pilot case study sites, our HEDAT was further refined by testing its application in regions of Queensland known to experience more extreme heat, humidity, and/or cyclones. We visited a further eight ACFs in Southeast Queensland (Bethania, Brassall, Carina, and Wynnum), Central Queensland (Mackay East and Mackay North), and Far North Queensland (Cairns and Mareeba) and incorporated facility managers' feedback and our experience to refine and finalize our HEDAT.

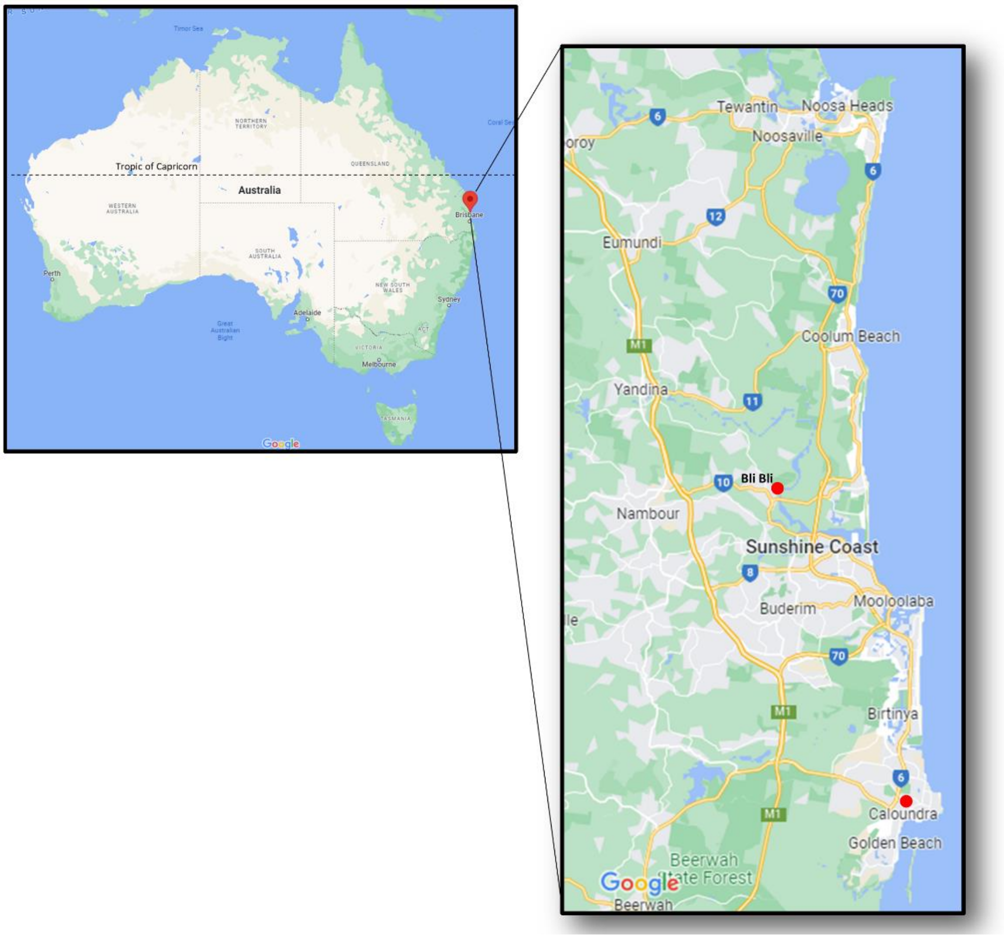

Figure 2. Location of Sunshine Coast and ACF case study sites (Image Source: Google Maps).

4. Results

4.1. Bli Bli Aged Care Facility

The Bli Bli ACF has a capacity of 92 beds and occupies approximately 3.7 ha with a moderately sloping easterly aspect, adjacent to low-density residential single lots, and a significant open space (Environmental Reserve). The site features seven low-set, detached residential complexes, including one memory support unit and a central administrative and activity center. Situated approximately 6.2 km from the Australian coastline (see Figure 2), the Bli Bli ACF is subject to the dominant onshore south-easterly breeze.

Four residential complexes are connected to the central administrative and activity center by covered walkways (Figure 3). The horizontal and vertical surfaces at the Bli Bli ACF are typically concrete pathways mostly shaded with permanent roofed structures connecting independent residential units. Concrete pathways also provide circuitous walkways around the southeast and eastern perimeter, though they need to be wider in places to support two people walking side-by-side. For the Memory Support Center, a concrete pathway partially covered by the building eaves and with limited sections with handrail supports facilitates residents' circumnavigation of the building. All buildings comprise cavity brick walls (medium to dark colors) typically exposed to direct sunlight. Limited pathway connections exist between complexes and the street/neighborhood pathway network. Thermal camera images demonstrate higher temperatures for surfaces without shading than those shaded; exposed areas of lawns are likewise hotter surfaces than shaded pavements (see Figure 4).

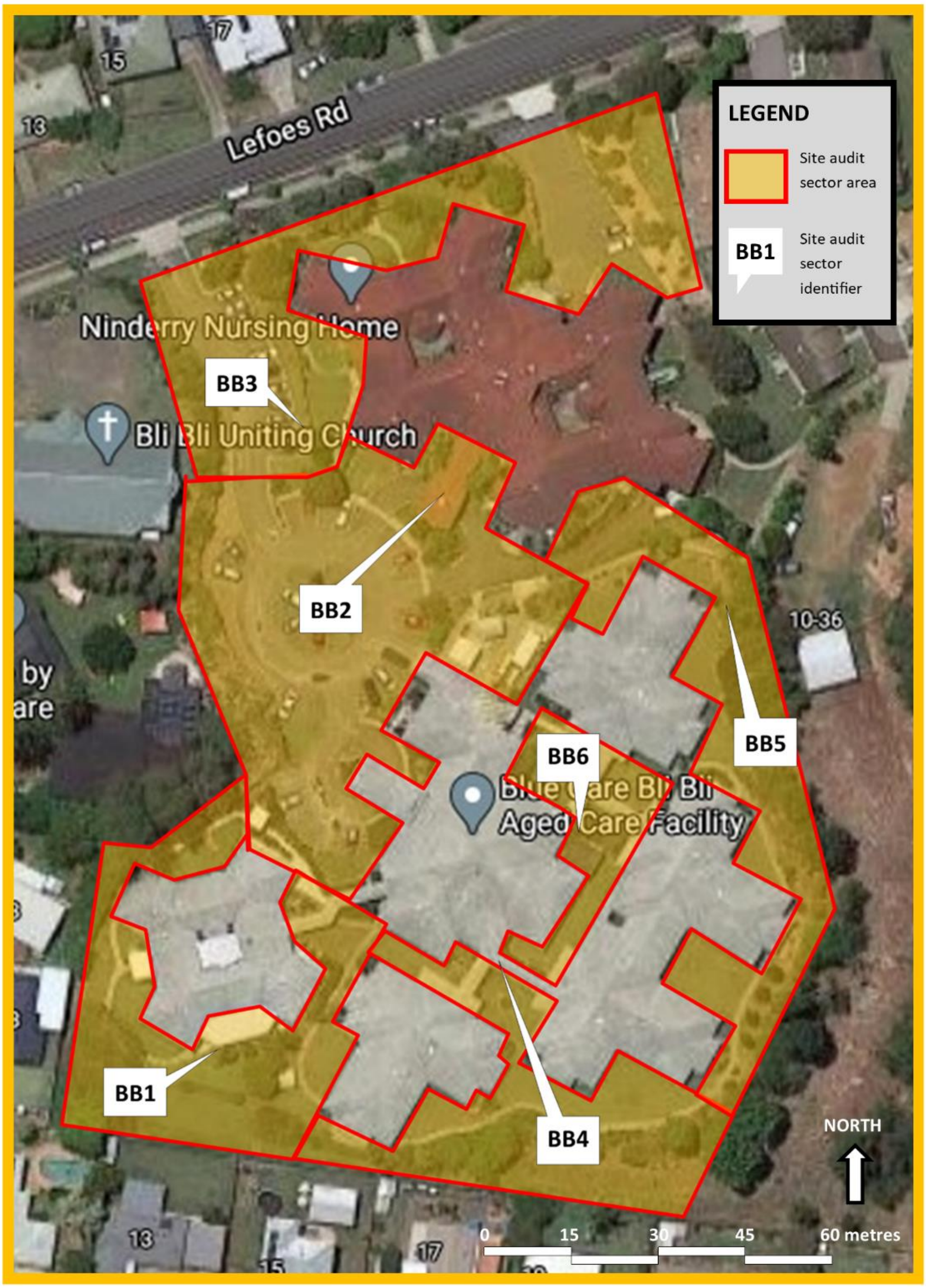

Figure 3. Bli Bli Aged Care Facility site image with audit sector assignment (Image Source: Google Maps).

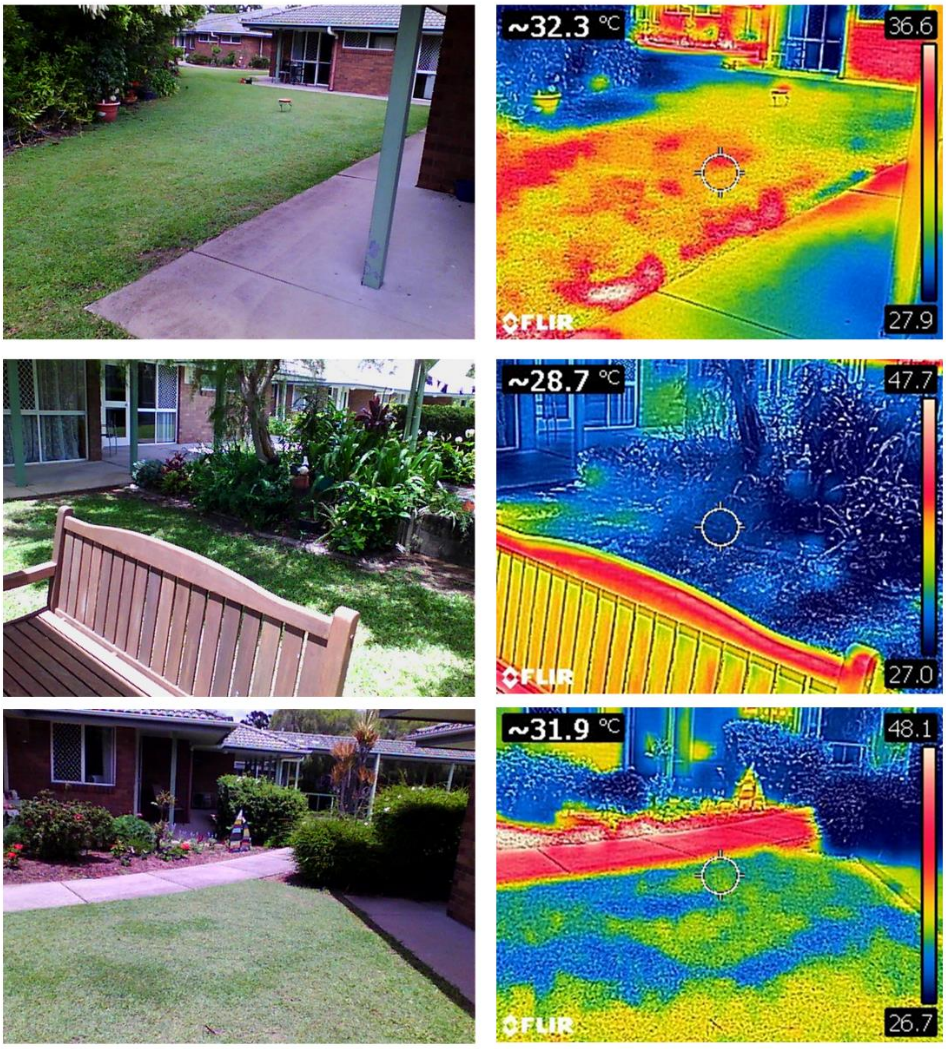

Figure 4. Thermal images and corresponding site photos for Bli Bli ACF in sectors BB5 (**top** and **bottom**) and BB6 (**center**). Thermal images were taken in the summer (29 January 2021) between 10:45 a.m. and 12:15 p.m. (Image Source: Author). Refer to Supplementary Materials for additional images and locations taken.

Our HEDAT reveals that a vegetated buffer area to the eastern property boundary provides an opportunity to enhance a biodiversity corridor, connecting the ACF site to the adjacent Wetlands Sanctuary. This area also provides a moderate level of shading to an eastern perimeter and supports urban wildlife, particularly the Australian Brush Turkey. The evaporative cooling infrastructure at the Bli Bli ACF is limited to one water feature, supported with overhead fans, adjacent to the patio area adjoining the central complex and dining area. The shading structures at the Bli Bli ACF include fixed permanent structures shading connecting pathways between central facilities and residential units, retractable shade sails (over a synthetic lawn area provided for putting/bowling activities), and trees.

For urban cooling, access, and safety at the Bli Bli ACF site, by sector, the HEDAT revealed that the provision of surfaces, vegetation, and shading structures for most sectors were rated fair (3) to good (4) or very good (5)—refer to Supplementary Materials and Table 2. Notable were materials that retain heat: concrete pavements, synthetic lawns, timber bench seats, and exposed areas of woodchip/bark garden mulch. The provision of evaporative cooling methods was consistently very poor (they were not present except for Sector BB6). Conversely, the Bli Bli ACF site represents the provision of an environment that supports accessibility and positive perceptions of safety, with all sectors rating from good (4) to excellent (6). For Bli Bli, pathways are wide enough to accommodate assistance devices (UD), with frequent rest spots (UD), wayfinding through decorative signs (UD), and visibility from main building outlooks (CPTED).

Table 2. Summarized HEDAT results for Bli Bli.

Criteria	Score [1]					
	BB1	BB2	BB3	BB4	BB5	BB6
Horizontal & Vertical Surfaces	4	3	3	4	4	4
Vegetation	3	3	3	3	3	3
Evaporative Cooling Methods	1	1	1	1	1	4
Shading Structures	5	2	4	4	5	4
Universal Design & CPTED	5	4	4	5	5	6
Overall Rating	4	3	3	4	4	4

[1] Scores were assigned 1 through 7, with each corresponding to a qualitative term (1—Very poor; 2—Poor; 3—Fair; 4—Good; 5—Very good; 6—Excellent; 7—Exceptional). Refer to Supplementary Materials for the completed (detailed) HEDAT.

These results highlight a clear priority to take action to address heat retention, particularly for Sectors BB2 and BB3, which are not performing well because of the heat retained in surfaces and the limited provision of vegetation and shade structures. At the site level, these settings contain the majority of unshaded vehicular pavements, without separated pedestrian accessways, that offer residents, staff, and visitors the least comfortable environment to transit through or occupy.

4.2. Caloundra Aged Care Facility

The Caloundra ACF has a capacity of 114 beds and occupies approximately three hectares with a gently sloping easterly aspect, adjacent to low-density residential single lots, and a significant open space (Environmental Reserve). The site features eight low-set, detached residential complexes arranged as two clusters of buildings (*Waroona* including a memory support unit to the south; *Aminya* to the north), with each cluster positioned around a central administrative and activity center (see Figure 5). Situated approximately three kilometers from the Australian coastline (see Figure 2), the Caloundra ACF is subjected to the dominant onshore south-easterly breeze.

Five residential complexes are connected to *Waroona* by covered walkways. The horizontal and vertical surfaces at the Caloundra ACF are typically concrete pathways somewhat shaded with permanent roofed structures connecting independent residential units with the central facilities. Concrete pathways provide direct access between residential units and central facilities. Within the Memory Support Center, a narrow, short-loop concrete pathway facilitates residents' circumnavigation within the courtyard. However, it is only partially shaded by tall open canopy trees and is too narrow for an attendant to walk beside a resident to pass each other, especially if using a mobility aid, and has limited sections with handrail supports. As with Bli Bli, all buildings comprise exposed cavity brick walls (medium to dark colors), and these are typically exposed to direct sunlight from most aspects. As expected, thermal camera images demonstrate higher temperatures for surfaces without shading (see Figure 6) and materials that retain heat: concrete pavements, non-irrigated areas of lawn, synthetic seat cushions, exposed brickwork, and exposed areas of gravel/stones used for garden mulch.

A vegetated buffer area to the west (for noise abatement) and northern site boundaries provide an opportunity to enhance a biodiversity corridor connecting to the adjacent parkland (Ben Bennett Bushland Park). This area also provides a high level of shading to the western perimeter and supports urban wildlife. The evaporative cooling infrastructure at the Caloundra ACF is limited to two small (domestic scale) water features within the Memory Support Unit courtyard. The shading structures at the Caloundra ACF include fixed permanent structures shading connecting pathways between central facilities and residential units, and trees.

For urban cooling, access, and safety at the Caloundra ACF site, by sector, the HEDAT revealed that the provision of surfaces and vegetation were rated fair (3) to good (4) while shading structures for most sectors rated mostly very good (5) or excellent (6)—see Table 3. As we observed for the Bli Bli case, notable again were materials that retain heat: concrete pavements, synthetic lawns, timber bench seats, and exposed areas of river gravel/stone or woodchip/bark garden mulch. The provision of evaporative cooling methods was consistently very poor (they were not present except for Sector C8). Conversely, the Caloundra ACF site represents the provision of an environment that is well-shaded and supports accessibility and positive perceptions of safety, with almost all sectors rating from good (4) to excellent (6).

The HEDAT results for the Caloundra ACF reveal that the existing external setting presents challenges for a comfortable, safe, and accessible environment to transit through or occupy. Those sectors with ratings of fair (3) or less present residents, staff, and visitors to the Caloundra ACF with areas that are generally challenging to navigate and/or access safely (UD) and securely (CPTED). Actions in these sectors aim to progressively enhance their accessibility and mobility through providing pathways (UD), resting areas (UD), and wayfinding items (UD/CPTED). These results also highlight a clear priority to take action to address heat retention, especially for Sector C4, which is not performing well because of the heat retained in surfaces and the limited provision of vegetation and shade structures.

Figure 5. Caloundra Aged Care Facility site image with audit sector assignment (Image Source: Google Maps).

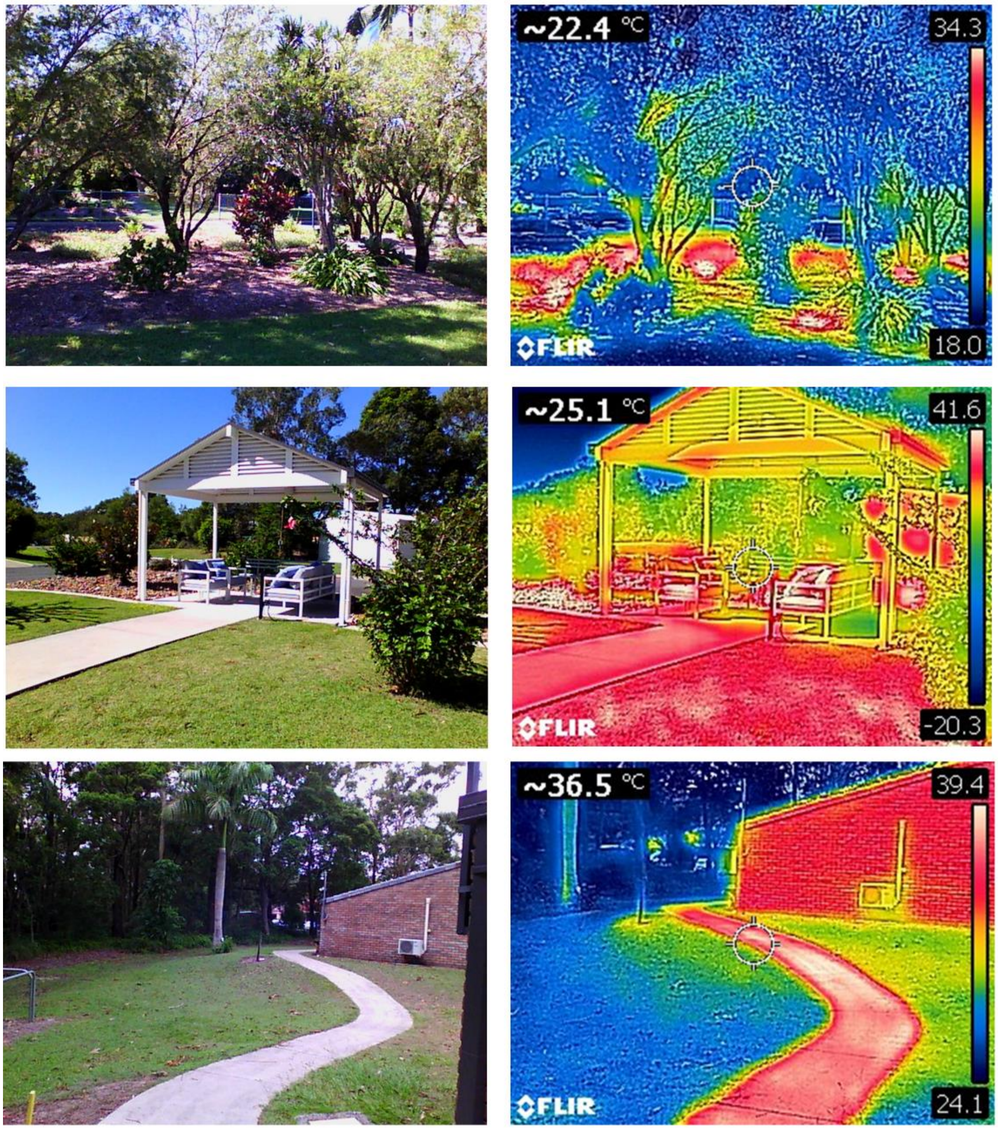

Figure 6. Thermal images and corresponding site photos for Caloundra ACF in sectors C4 (**top**), C3 (**center**), and C1 (**bottom**). Thermal images were taken in the summer (28 January 2021) between 2:00 p.m. and 3:30 p.m. (Image Source: Author). Refer to Supplementary Materials for additional images and locations taken.

Table 3. Summarized HEDAT results for Caloundra.

Criteria	Scores [1]							
	C1	C2	C3	C4	C5	C6	C7	C8
Horizontal & Vertical Surfaces	3	4	2	3	3	4	3	3
Vegetation	3	3	3	3	3	3	3	3
Evaporative Cooling Methods	1	1	1	1	1	1	1	3
Shading Structures	6	5	5	4	5	5	6	6
Universal Design & CPTED	3	5	5	4	4	4	4	6
Overall Rating	4	4	4	4	4	4	4	4

[1] Scores were assigned 1 through 7, with each corresponding to a qualitative term (1—Very poor; 2—Poor; 3—Fair; 4—Good; 5—Very good; 6—Excellent; 7—Exceptional). Refer to Supplementary Materials for the completed (detailed) HEDAT.

4.3. Strategies for Environmental Design Modifications

Strategies for improving urban cooling have been proposed for each case study site to support modifications in the environmental design. Mitigation actions aim to reduce heat and thermal discomfort through improved urban cooling, access, and safety consistent with the environmental design approaches used to inform the HEDAT [19,58,61,72]—refer to Table 1. The strategies for improving horizontal and vertical surfaces, vegetation, evaporative cooling, and shade provision, with their rationale, are provided in Table 4.

Table 4. Mitigation strategies for Bli Bli and Caloundra ACFs to reduce heat and thermal discomfort through improved urban cooling, access, and safety.

Strategy	Design Solution/s & Rationale
1. Horizontal & Vertical Surfaces (a) Improve shading of vertical surfaces and pathways to reduce heat emission, particularly large expanses of asphalt vehicle pavements and dark brick walls facing west. (b) Increase shade over exposed concrete pathways with places for rest.	**Shade sails:** While expensive to supply & install in the short term, they do provide immediate results while time is needed to establish shade trees. With a lifespan of 15–20 years, shade sails can provide shade, reduce evaporation, and support new planting to establish. **Shade structures**: Permanent shading structures should be considered where it may not be practical or feasible to establish large trees (adjacent structural pavements and large expanse of asphalt in car parking areas). Market umbrellas offer a temporary solution.
(c) Provide bio-swales and convert lawn areas to planting to improve permeability and reduce maintenance	**Bio-swales**: These are linear, vegetated swales (channels) across the landscape and planted to retain stormwater runoff and filter debris and nutrients (pollutants).
2. Vegetation (a) Increase the provision of raised garden beds and planter boxes to support equitable access, use & low physical effort. (b) Convert lawn areas to gardens to increase permeability and reduce maintenance.	**Raised gardens, planter boxes & other containers**: These support access to a garden where mobility or physical movement is limited. Various structures, including recycled timber storage/pallets, can be adapted & include wheels for relocation as needed. **Rain gardens**: "A rain garden is a system that collects water from paving, hard surfaces, and roofs, and puts it through a filtering mechanism that removes nutrients and pollutants. The water can then be used to irrigate the garden or can pass through the filtering system and be released into the drainage system." [79]
(c) Increase the diversity of native species and establish connections to adjacent vegetation corridors for enhanced biodiversity and climate change resilience. (d) Replace specimens requiring regular pruning with more appropriate (native) species.	**Native grasses**: Lawns can be replaced with large, planted areas of native grasses to improve surface water filtration, support biodiversity, and increase permeability. **Groundcover plants:** Groundcover plants help to reduce weeds and keep the soil moist and cool. Select low-maintenance prostrate forms—those species that are native, fast-growing, and hardy to local soil and climatic conditions (e.g., drought/frost/heat) and will spread across the surface to cover the mulch and soil.
(e) Maintain groundcover species to prevent exposed areas of woodchip/bark mulch.	
(f) Introduce vertical structures with climbers to replace hedged plants where screening is required Introduce rain gardens adjacent to large pavement areas.	**Climbers & Vertical Structures**: Providing cabling systems &/or horizontal battens to existing structures can support vegetation to shade walls and provide screening (for privacy) and cooling.
3. Evaporative Cooling Methods (a) Introduce evaporative cooling methods (e.g., water fountains and other water features) across the site in shaded/semi-shaded locations (with water tanks to maintain supply). (b) Provide evaporative cooling methods to maximize equitable access and user experience with low physical effort.	**Water features:** Formal water features at key points of arrival or contemplation can enhance visual amenities and support calming and relaxation. Formal water features need to be supported by a water source for topping-up water levels and cleaning, as well as electricity for circulation pumps. Raised structure improves accessibility and interaction for all. Water features also support the biodiversity of our urban habitat and often attract urban wildlife, including birds and water dragons.
(c) Lift existing tree canopies (remove the lower branch to form clear trunks) to support airflow and evaporative cooling.	**Pruning for air circulation**: Existing trees with low branches can be pruned to achieve a clear trunk for improved visibility and to increase air circulation for cooling.

Table 4. *Cont.*

Strategy	Design Solution/s & Rationale
4. Shading Structures (a) Maintain and provide additional shading structures. (b) Relocate bench seats to shaded positions that also optimize viewing of high amenity areas. (d) Convert transparent roof structures to solid, non-transparent materials with provision for climbing plants to enhance shade and cooling. (e) Provide horizontal battens to the top sections of shade structures to increase shading and support climbing vegetation to enhance shade density and aid cooling through evapotranspiration.	**Permanent Shade:** Permanent shade structures require structural engineering design and certification to ensure they can withstand extreme weather conditions (storms & strong winds). They also require sizable footings for secure anchoring, so they should be installed prior to constructing pavement or establishing gardens and trees that surround the proposed structure. **Semi-permanent shade**: Semi-permanent shade structures such as shade sails and other tensioned membranes) also, require structural engineering design and certification to ensure they can withstand extreme weather conditions (storms & strong winds). They also require sizable footings for secure anchoring, so they should be installed prior to constructing pavement or establishing gardens and trees that surround the proposed structure. Membranes/sails occasionally fail during severe winds but can be replaced easily. **Temporary shade:** Market umbrellas provide temporary shade solutions at a very low cost. They can also be moved to suit solar aspects & are readily stored indoors during windy conditions.
(f) Increase tree planting (native species) to provide year-round shade.	**Trees:** Trees are typically the cheapest solution to providing shade however require 5–10 years to establish. Species selection and confirmation of underground service location are critical to prevent problems later with potential root intrusion and branch failure.
5. Personal Safety & Access (a) Provide direction cues to support navigation and orientation around the facility.	**Directional Markers**: Totems, pavement &/or wall decorations, and vertical objects in a distinguishable color/shape (e.g., mailboxes) can be applied to support wayfinding and landmarks that help orientate visitors and residents using the pathway network.
(b) Provide supporting structures to access ways for resting and/or steadying while moving along the route.	**Handrails:** Handrail supports to one or both sides of pathways at regular intervals can be installed to support pedestrians with limited movement capabilities and difficulties maintaining balance and/or motion. **Pathways:** Pathways should be smooth, non-slip, and even surfaces on flat or gentle grades, at least 1.5 m wide, to allow a carer or attendant to walk beside the resident or residents to pass each other. **Bench Seats:** Installation of fixed seating (e.g., bench seats) adjacent to pathways and at regular intervals can be installed to support pedestrians with limited movement capabilities and difficulties maintaining balance and/or motion as places of rest and recovery.
(c) Maintain clear sightlines from internal activity areas and accessways to external areas for casual surveillance.	**Plant Selection:** Select tree and shrub species that support formative pruning to achieve a clear trunk to a minimum of 1.5 m high from ground level. **Formative Pruning**: Prune lower branches of trees and shrubs to achieve a clear trunk to a minimum of 1.5 m high from ground level.

Prioritized mitigation works are proposed to be sequenced to address the locations that have demonstrated the greatest levels of discomfort for each case site in the first instance, proceeded by works that require the greatest extent of ground disturbance (i.e., installation of structures/footings, and/or new pavements), substantial tree planting and/or water features. Planting, furniture, and signage are considered final/finishing works. The proposed priorities of mitigation actions for the ACF case study sites mostly comprise landscape works (e.g., planting, garden construction, seat installation), pavement refurbishment to improve access and support activities, and provision of shade structures as the highest priority for immediate impact in mitigating heat stress.

5. Discussion and Conclusions

Our study offers a novel approach to the auditing of built environments and their role in supporting urban cooling, as well as achieving UD for equitable access, inclusion, and personal and physical safety. The HEDAT was used to assess the existing condition and inform strategies for improvement as part of a heat adaptation planning process at ACFs. These data collection methods are suited to ongoing monitoring; auditing should be repeated on a regular basis, particularly on the completion of major works (such as new assets, facilities, or landscape works) or disturbances (e.g., storm damage). Monitoring to detect changes (improvements or worsening of heat, thermal comfort, access, and safety) will support ACF providers in adapting to climate change with evidence-based decision-making to marshal and direct financial resources to the areas that need it most: those which expose residents, staff, and visitors to extreme levels of discomfort.

Responding to calls from Shooshtarian et al. [49] our research helps to fill a gap by examining outdoor thermal comfort using case studies of regional areas and draws from qualitative analysis (including observation) to better understand perceived environmental quality and physical attributes of spaces and outdoor thermal conditions. We acknowledge that comfort needs to consider the relationship between air temperature and humidity. Our larger study, which is to be reported separately, measures thermal comfort using weather sensors for air temperature and relative humidity. Our HEDAT results demonstrate that the existing external environments of our case study ACFs include GI, typically in the form of lawns, gardens, and trees. However, while GI enhances visual amenities and supports passive recreation, our HEDAT results reveal limitations in its effectiveness in achieving urban cooling, enhancing biodiversity, and/or supporting perceptions of personal safety. Further, while some shading structures and pathways exist for access and mobility, in most cases, they are too narrow to be safe and prevent carers from walking side-by-side with residents. The condition of GI suggests that resources allocated to GI maintenance and enhancement are highly constrained.

Limitations for this research included restricted access to the sites during COVID-19 lockdowns. Time was limited to self-reports by residents and staff of their comfort and use, the researchers' brief observations of use by residents, staff, and visitors, and discussion with staff and residents about possible solutions during intermittent visits for data collection. Future audits may also benefit from feedback from residents, staff, and visitors to identify how the environment has changed or is used differently since previous audits. While the HEDAT was completed by the project Research Fellow (an experienced Landscape Architect) in collaboration with another research team member for corroboration and to determine ease of tool use, it may also be administered by site management or grounds staff, with some guidance. We recommend that the HEDAT be applied at the design phase for projects concerning new works and/or ACF re-development or extension. As our case study sites are located within a humid subtropical climate, their application to locations in hot climates needs to be tested and validated through future research.

In conclusion, this article reports on the HEDAT component of a study that used multiple methods to test and validate the approach and feasibility for adaptation planning which could then be applied across a range of climatic variations at a regional or national scale. Environmental audits can provide a basis for future monitoring but should also be considered in the context of site-level weather conditions and staff and residents' reports of use and thermal comfort—to ascertain the likely contribution of environmental design to thermal comfort. The weather data was used to measure heat in each sector (the hottest spots) to identify which sector within each facility should be prioritized for action/intervention.

This research is important; it demonstrates that when GI is provided to enhance visual amenities and support passive recreation, opportunities can be overlooked to achieve urban cooling, enhance biodiversity, or enhance perceptions of personal safety. Further, while shading structures and pathways are often included for access and mobility, effectiveness can be affected by an understanding of how to address the complexity of elderly needs and limited resources allocated to GI maintenance and enhancement.

Future research directions should also consider neighborhood and city scales, especially areas inhabited by concentrated populations of those vulnerable to heat stress. Our study offers a novel approach to auditing the built environment and the role of GI in supporting urban cooling for heat adaptation planning. It contributes to social equity by avoiding unintended consequences and by achieving equitable access, inclusion, and personal and physical safety.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/land12020514/s1, Site Photos; complete audit results (detailed scoring and observations) applying the Hybrid Environmental Design Audit Tool for each case study site: Bli Bli; Caloundra.

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