

# 11

## HOT SPRING LANDSCAPE DESIGN FOR SUSTAINABLE WELLNESS TOURISM AT FELDA RESIDENCE SUNGKAI, PERAK

Nor Maziatul Afiqah Mazlan, \*Putri Haryati Ibrahim & Mazlina Mansor

Department of Landscape Architecture, Kulliyyah of Architecture and Environmental Design, International Islamic University Malaysia

### ABSTRACT

Hot springs are natural geothermal phenomena that offer recreational and therapeutic benefits. The project investigates the potentials and proposes hot spring landscapes as community-based oriented areas for rehabilitation and enjoyment. The methodology combines site observations, field surveys, and secondary data analysis to examine existing conditions and support relevant findings. Through precedent studies, the paper explores design strategies that optimise hot spring landscapes for sustainable tourism and local engagement. The findings reveal that the site possesses strong potential to function as a rehabilitation and therapeutic centre, enriched by its natural surroundings. Beyond the hot spring itself, the integration of nature trails and environmental education opportunities enhances its value as a holistic healing environment. The design proposal therefore emphasises not only the therapeutic effects of mineral-rich waters but also the creation of diverse public healing spaces that harmonise conservation goals with community well-being. By incorporating health tourism elements and prioritising sustainable practices, this study contributes to future development models that position hot springs as balanced destinations for both environmental protection and human wellness.

**Keywords:** Community well-being, Hot spring landscape, Rehabilitation, Recreational, Therapeutic

\*Corresponding author: [putri@iium.edu.my](mailto:putri@iium.edu.my)

### PROJECT INTRODUCTION

Hot springs are natural geothermal features known for their recreational and healing benefits, especially due to their mineral-rich waters that help improve circulation, relieve pain, and support rehabilitation. As eco-tourism grows, many hot spring sites are being developed to attract visitors and support local economies. However, this can put pressure on the environment, leading to habitat loss, pollution, and reduced natural value if not carefully managed (Baloch et al., 2022; Wang & Lin, 2021). Since these sites often support community health and therapy, sustainable landscape planning is crucial. This research focuses on designing hot spring landscapes that enhances rehabilitation and recreation; while exploring how current landscapes are used and how thoughtful design can improve user experience and long-term sustainability.

#### Site Issues

##### Accessibility

The site is situated in Sungkai, a rural part of Perak, which could make it difficult for visitors to access the site without private transport. The site has limited public transportation options and not universally accessible especially for elderly. Other than that, the site has unclear directions that might discourage potential visitors.



##### Flooding

The site also faced flooding problem especially during heavy rainfall season due to the low-lying areas or near water sources where underground water surfaces that collect runoff during heavy rains.



### Site Location



Figure 1: Site location showing key plan, location and site plans.

### Site Background

Felda Residence Hot Springs in Sg. Klah is a tropical retreat renowned for its natural, mineral-rich hot springs fed by underground geothermal activity. The site also has over 300 natural hot spring water sources. Originally an oil palm farm, the site was transformed by FELDA in 2003 to boost its rural tourism potential. This serene escape not only highlights the therapeutic qualities of the hot springs but also promotes economic development, environmental conservation, and community connection. Figure 1 shows the key plan, location plan and the site plan of the proposed site.



## LITERATURE REVIEW

According to Zhou et al. (2023), hot spring is a location where geothermal water naturally emerges onto the Earth's surface, causing a visible hot water flow. A hot spring develops naturally when heated groundwater rises to the Earth's surface. It has a higher temperature than the human body which is typically about 40°C or more. Apart from the high temperature, the water contains significant levels of dissolved minerals, including calcium, sodium, sulfate, chloride, and silica (Rosli et al., 2022).

A study by Barrick (2007) stated that, hot spring landscapes are unique geothermal environments where groundwater heated by the earth's interior rises to the surface, creating naturally warm pools. The surrounding landscapes contain geysers, hot springs, mud pots, fumaroles, and other hydrothermal features. They are important natural resources that has potential for recreation, economic, scientific, and educational benefits. These landscapes have been valued for centuries for their therapeutic, recreational, and cultural significance (Erfurt, 2021). Other than that, historically, hot springs have been used as natural spas, offering health benefits due to the minerals in the water, which are believed to aid in the treatment of various ailments, including skin conditions, joint problems, and muscle relaxation (Erfurt, 2021).

## METHODOLOGY

This study used the qualitative approach, combining both primary and secondary data for a comprehensive analysis. The primary data came from a semi-structured interviews, site observations, and field surveys, offering direct insights into how the hot spring landscape is used for rehabilitation, recreation, and health. While, the secondary data were gathered from literature reviews, document analysis, and online sources, allowing for comparison with similar sites. The data helps in identifying design strategies to improve user engagement and sustainability. The research aim focuses on understanding the community's relationship with the hot spring, exploring hot spring landscape for health benefits, cultural value, and potential for sustainable design.

## SITE INVENTORY AND ANALYSIS

### 1. Site Context

Figure 6 and 7 shows the site contexts in term of range in distance and landmarks available at the site's vicinity.

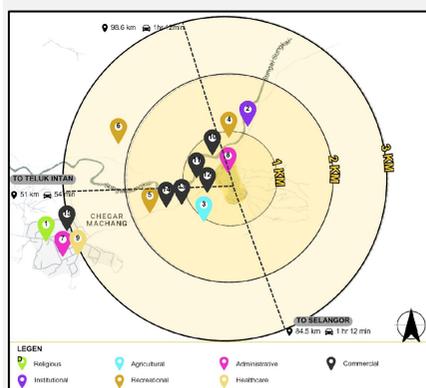


Figure 6: Site context map



Figure 7: Site context

## PRECEDENT STUDIES

Figure 4 shows the aerial view of **Poring Hot Springs**. The site is a well-known natural hot spring located at the foot of Mount Kinabalu in Ranau, Sabah. Its hot water contains sulfur, which helps refresh and relax the body. Visitors can choose between outdoor pools, indoor tubs, or private heated pools. The water can reach up to 70°C on hot days, but usually stays between 40°C and 60°C.



Figure 4: Poring Hot Springs



Figure 5: Honggae Hot Spring

Figure 5 shows the aerial view of **Honggae Hot Spring**, Panzhihua, China. The site is well-known for its high mineral content and natural medicinal properties. Nestled in an area rich in geothermal resources and picturesque landscapes, it attracts tourists and health-conscious visitors to enjoy its radon-rich waters, which offer a variety of health advantages, notably for arthritis and skin diseases.

### 2. Site Zoning

As shown in Figure 8, the site is divided into different zones for therapy, recreation, accommodation, and administration. The hot spring pools and reflexology paths are the main features for healing and relaxation. The recreational area is for families and leisure, while the accommodation and admin zones support overnight stays and daily operations. However, some zones are not well connected. Parts of the site also look old and need upgrades.

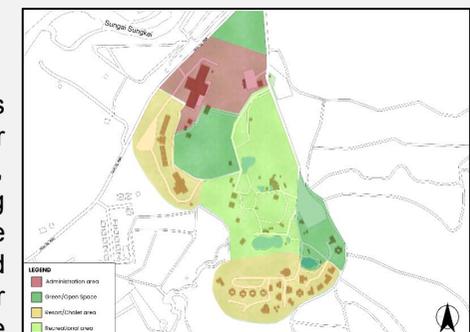


Figure 8: Site zoning map



Figure 9: Site zoning section

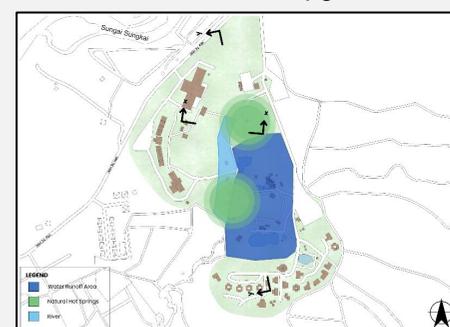


Figure 10: Hydrology map

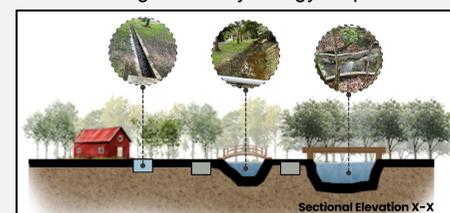


Figure 11: Hydrology section

### 3. Hydrology

The site has over 300 hot spring outlets that provide warm, mineral-rich water for therapy pools, foot paths, and egg-boiling spots (Figure 10). Natural rivers and rainwater also flow through the area, adding to its natural surrounding beauty. However, some parts of the site are easily flooded during heavy rain, causing problems for visitors and staff. Other than that, too much geothermal water is used that could also harm the environment. To fix this, the site needs better water control systems such as drains and ponds to reduce flooding and protect nature.

#### 4. Landform and Topography

The landform at the Felda Residence Hot Springs Sg. Klah ranges from 52 to 146 meters above sea level (Figure 12). The central area has gentle slopes, making it ideal for pools, paths, and relaxation spots. The steeper outer areas offer great views and are good for conservation. The natural shape of the land also helps with water flow and groundwater. However, the lower areas can flood during the rainy season, and steep slopes may face erosion. To improve the site, solutions like terracing, erosion control, and raised walkways can be added to protect the land and make the space more enjoyable and sustainable.

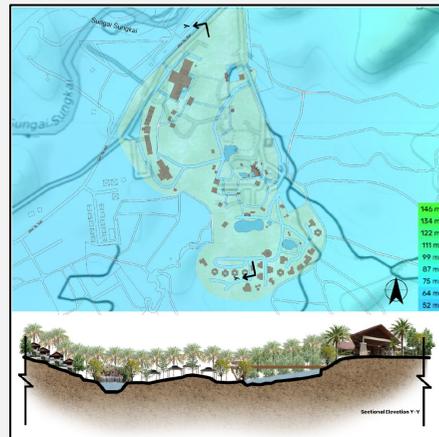


Figure 12: Topography map & section

#### 5. Geology and Soil

The geology and soil map at Felda Residence Hot Springs Sg Klah as shown in Figure 13 show unique base for the site. Figure 14 shows example of travertine rock at the site. These rock formations, formed by mineral-rich hot water, add beauty and educational value to the area. The soil is mostly sandy and loamy, which supports local plants and light structures. However, it is not strong enough for heavy buildings without special engineering. Also, the travertine rocks need to be protected during any development. Other than that, careful planning is needed to build facilities while preserving these natural features.

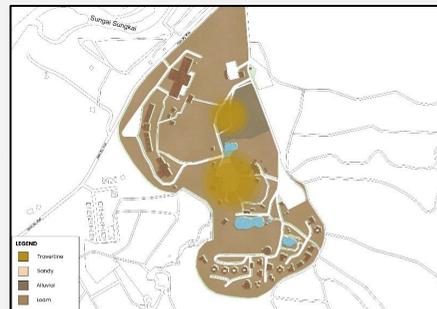


Figure 13: Soil & geology map



Figure 14: Travertine rock at site

#### 6. Microclimate

Figure 15 shows the microclimate map of the Felda Residence Hot Springs Sg. Klah. The site has a tropical climate, with temperatures between 25°C and 33°C and high humidity all year round. This warm weather supports outdoor and hot spring activities, making the environment feel more relaxing. Natural plants and water features also help cool the area. However, the midday heat can be too intense, especially during the dry season, while the rainy season can affect safety and access. To improve comfort, the site should include shaded areas like pergolas and trees, along with covered walkways to protect visitors from sun and rain.

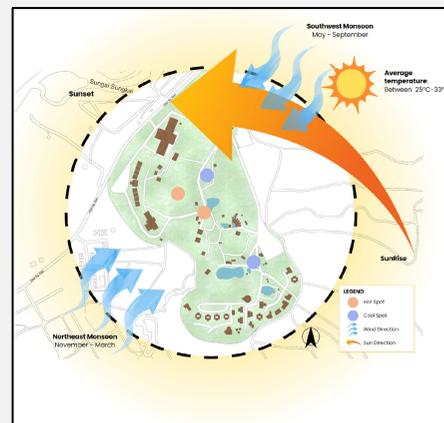


Figure 15: Microclimate map

#### 7. Accessibility

Access to the site mainly depends on Jalan Sg. Klah. Figure 16 shows that the site has two entrances: one for resort guests and buses, and another for regular visitors at the ticket counter. While this setup helps manage traffic, the lack of public transport makes the site hard to reach for those without private vehicles. During weekends and holidays, traffic can become congested, affecting visitor comfort. On-site, buggies and walking paths help with movement, but some paths are old and poorly marked, making navigation harder.

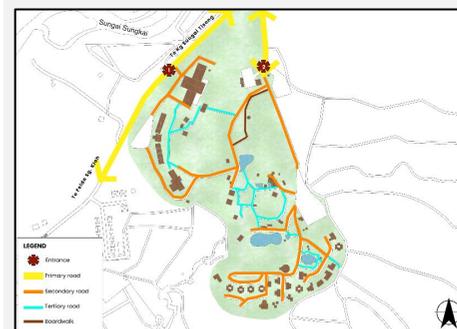


Figure 16: Accessibility map

#### 9. Vegetation

Figure 18 shows the native and ornamental plants available at the site such as *Frangipani*, *Beach Spider Lily*, and *Bird's Nest Fern* help cool the area, improve air quality, and add to the peaceful atmosphere. Some parts of the site have poorly maintained or plain landscaping, which reduces the site's visual and ecological value. Also, the planting lacks a clear theme that reflects its identity as a healing space.

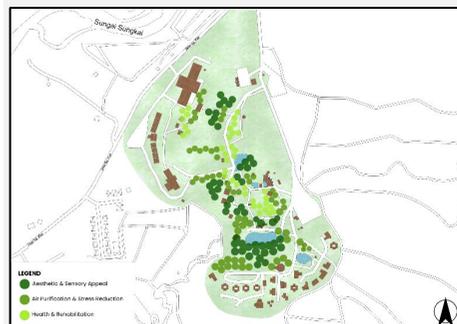


Figure 18: Vegetation map

#### 8. Facilities

The site offers various facilities for visitors, including hot spring pools for therapy, a children's water play area, reflexology paths, and boardwalks (Figure 17). These facilities is suitable for relaxing, healing, and family-friendly activities and shared experiences. Visitors can also stay overnight in chalets and resorts, which give access to the springs during quieter hours. However, many of the facilities are old and outdated, reducing their comfort and visual appeal. The site also lacks spaces for larger rehabilitation or wellness programmes.

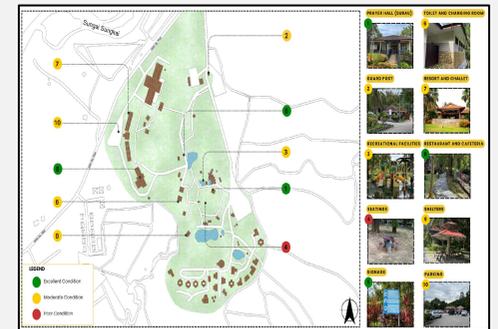


Figure 17: Facilities map

#### 10. Visual and Sensory

Figure 19 shows the overall visual and sensory map. Natural sounds like flowing water and rustling leaves at the site, contribute to the calming atmosphere. However, certain parts of the site reduce its sensory appeal, such as bad smells from the egg-boiling area and Animal Village. These issues affect the overall visitor experience.

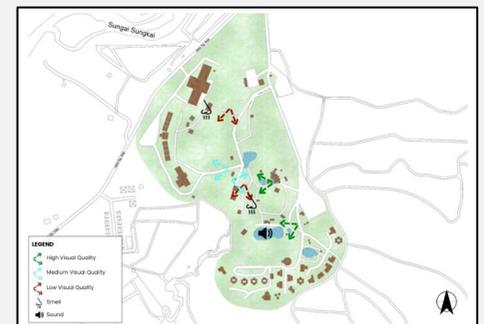


Figure 19: Visual & sensory map

## CROSS ANALYSIS

Table 1: Cross analysis

HOT SPRING LANDSCAPE CRITERIA	Vegetation	Hydrology	Geology and Soil	Topography	Microclimate	Accessibility	Facilities	View and Senses	Socio-Culture and Economic
Environmental Consideration	●	◐	●	●	●	◐	◐	●	◐
Therapeutic Value	◐	●	◐	●	●	●	●	●	●
Accessibility	○	○	◐	◐	●	●	●	●	●
Safety and comfort	◐	◐	◐	◐	●	◐	●	◐	●
Educational and Interpretive	●	●	●	●	◐	◐	●	●	●
Aesthetic and Cultural Design	●	●	●	●	●	●	◐	●	●

● Fully Suitable   
 ◐ Partially Suitable   
 ○ Not suitable

## SITE SYNTHESIS

The synthesis method entails assessing the site's potentials and constraints in order to identify major possibilities and problems. Table 1 shows the cross analysis of all elements. A synthesis map (Figure 22) was done by layering all of the scoring maps, resulting in a composite scoring map, which highlights locations with the most and least development potentials. This method provides a thorough awareness of the site's suitability for the future design.

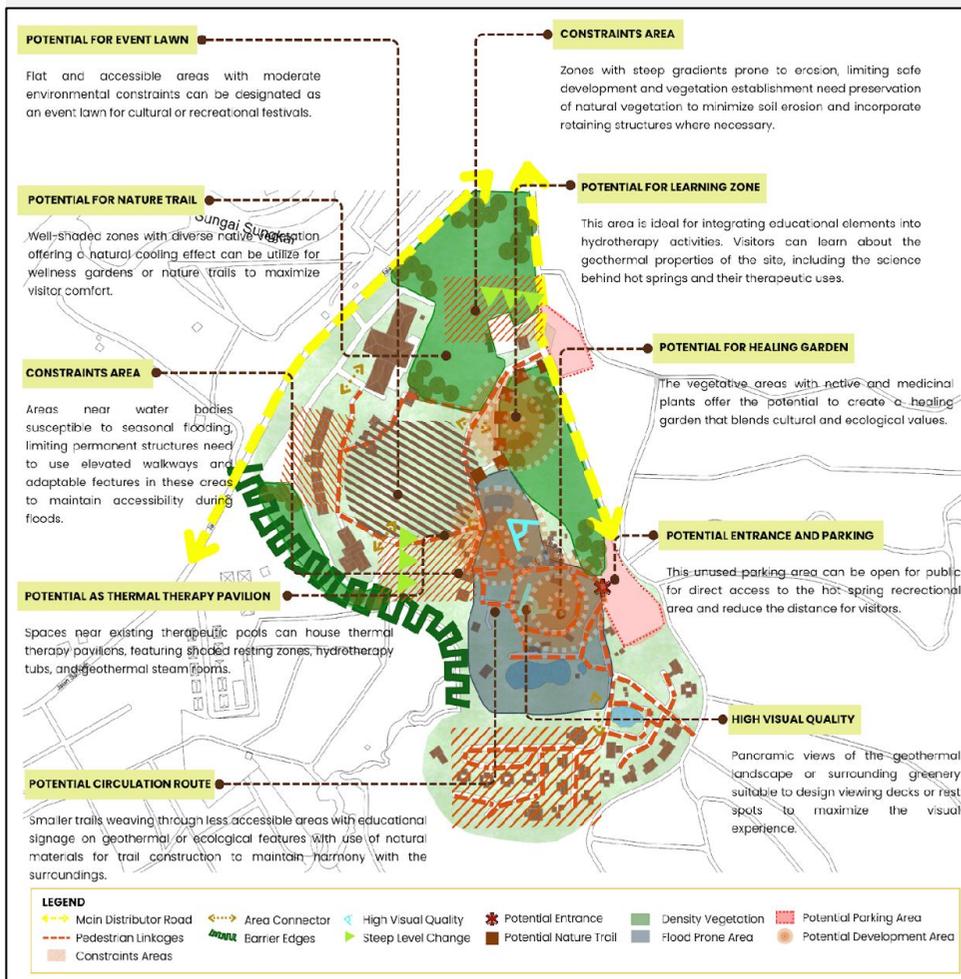


Figure 20: Composite synthesis map

## DESIGN STRATEGIES

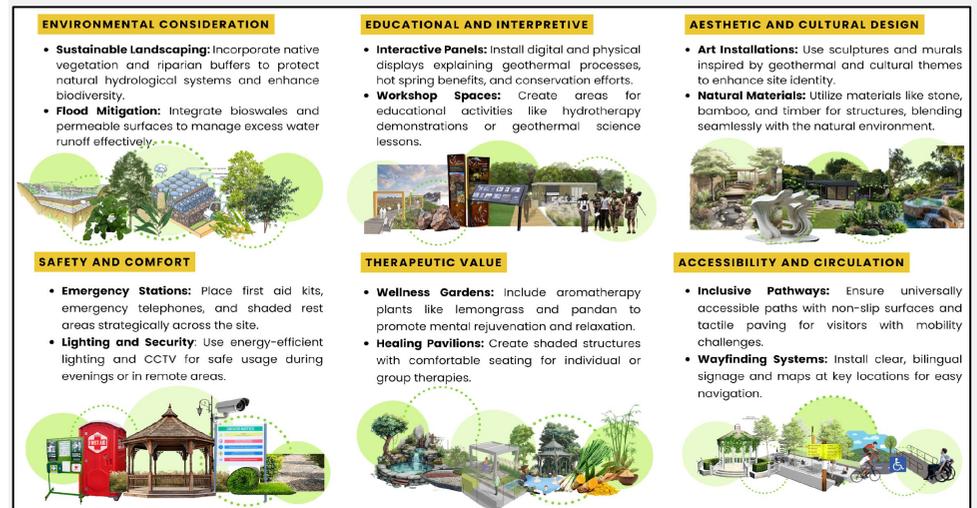


Figure 21: Design strategies

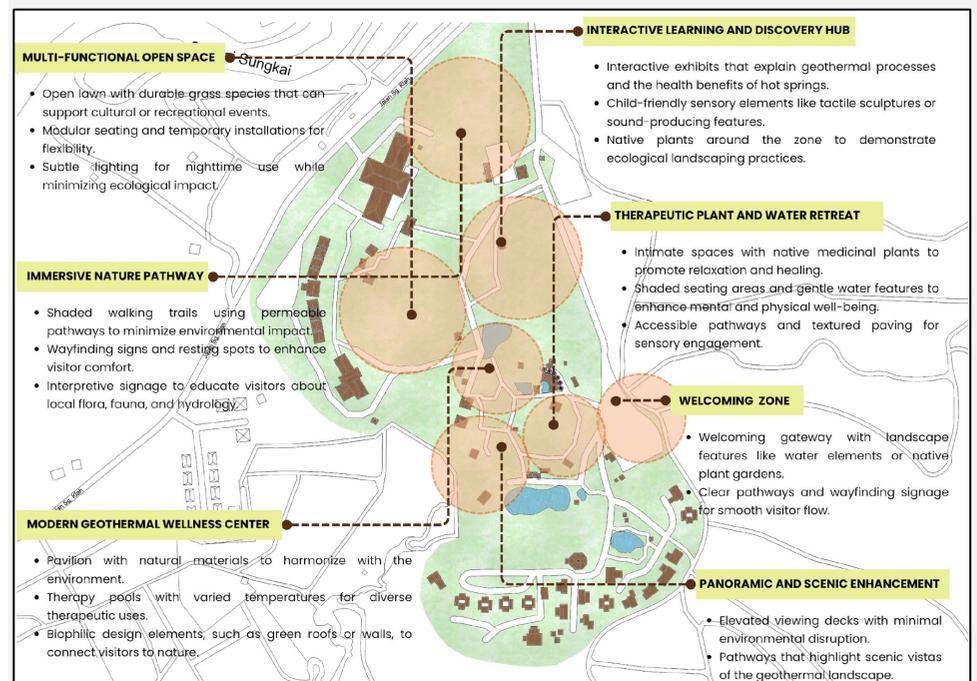


Figure 22: Synthesis map



Figure 23: Design ideas

## DESIGN DEVELOPMENT

### DESIGN CONCEPT

The chosen design concept, 'Thermal Vitae', is derived from two Latin words: *Thermal* meaning 'heat,' and *Vitae* meaning 'life.' This concept highlights the therapeutic qualities of natural hot spring water, emphasising its role in promoting health, relaxation, and overall well-being. The study plan to create different pool zones with various water temperatures to help with muscle pain, support skin rejuvenation or nerve therapy. The design also aims to reflect the natural flow of geothermal water through pathways, gathering areas, and landscapes, creating a peaceful and healing environment for both the body and mind.

### Design Aim

To design a hot spring landscape that harnesses the healing properties of thermal water through spatial and hydrotherapy-focused interventions, creating a restorative environment for rehabilitation, relaxation, and well-being while preserving the site's natural geothermal resources. Figure 24 shows the design strategies developed for Felda Residence Hot Springs, Sungkai, Perak.

### Design Objectives

- 01 To integrate geothermal water movement as a primary design element, shaping spaces for relaxation, rehabilitation, and sensory experiences.
- 02 To design a landscape that optimises natural thermal water circulation while ensuring ecological sustainability and minimal environmental impact.

### Design Strategies



Figure 24: Design strategies

## DESIGN PROCESS

Figure 25, 26, 27, 28, 29, 30 shows the overall design process involved in the study.

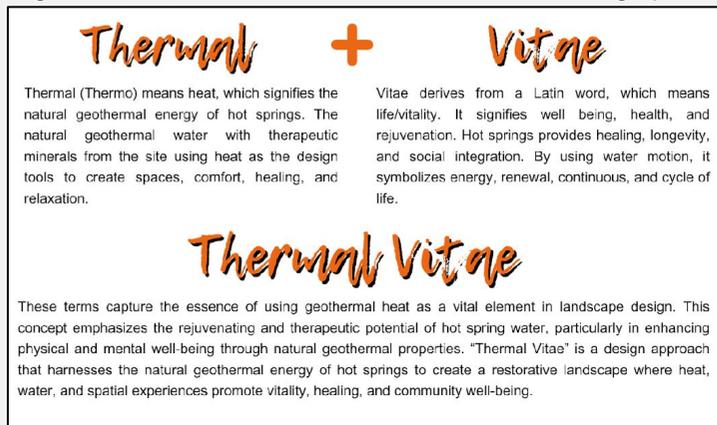


Figure 25: Conceptual breakdown

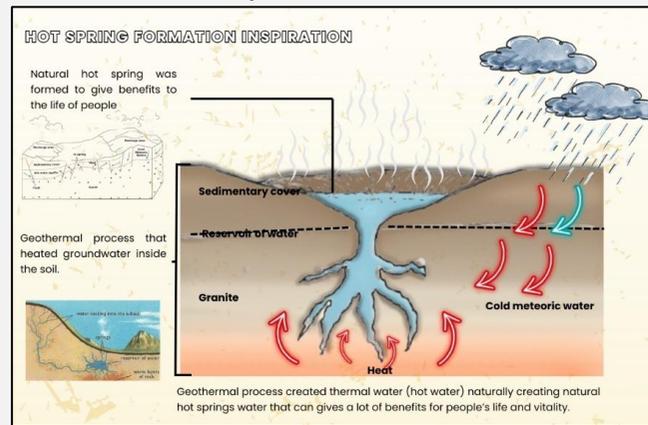


Figure 26: Hot springs formation

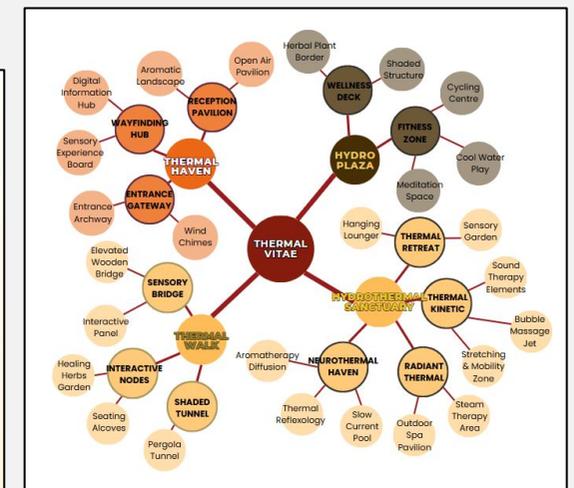


Figure 27: Space programming

### Functional Diagrams

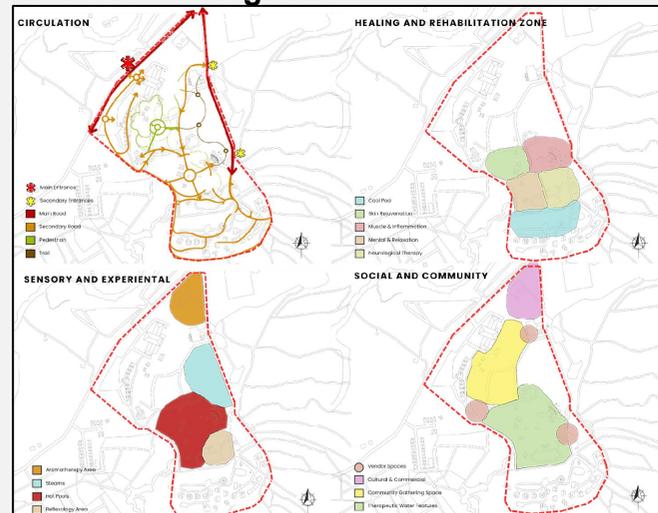


Figure 28: Functional diagrams

### Conceptual Plan

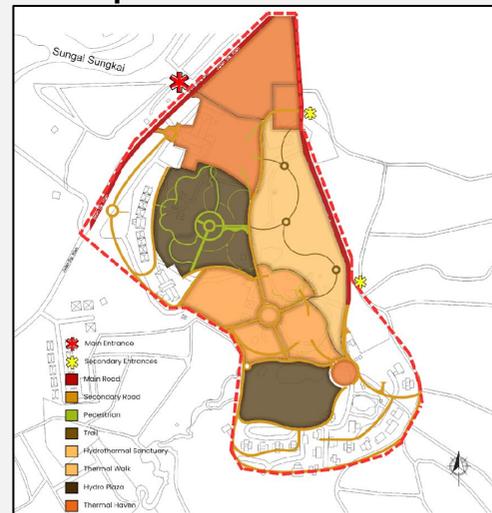


Figure 29: Conceptual plan

### Schematic Plan



Figure 30: Schematic plan

## PLANTING CONCEPT

The study proposed **Thermal Verdance** planting concept that blends the soothing qualities of hot springs with the vitality of lush greenery, forming a serene and restorative environment. *Thermal* represents the warmth of geothermal water, while *Verdance* symbolises the richness of flourishing plant life. Combined, they create a harmonious space that feels natural, calming, and deeply supportive of health and well-being. Figure 31 show the development of the planting strategies.

### Planting Strategies

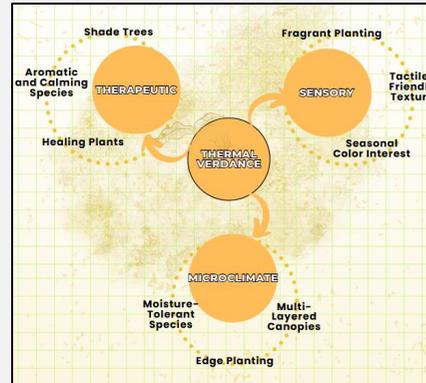


Figure 31: Planting strategies

## PRELIMINARY MASTER PLAN

The Preliminary Master Plan shown in Figure 32 represent the transforms the conceptual framework into a more defined spatial layout, dividing the geothermal environment into interconnected zones of healing, relaxation, and community wellbeing. This phase strengthens the fundamental design approach by matching spatial features to the flow of geothermal water and the therapeutic experiences it provides. Figure 33 and 34 shows the aerial view of the proposed design for Felda Residence Hot Springs, Sungkai, Perak.



Figure 32: Preliminary master plan

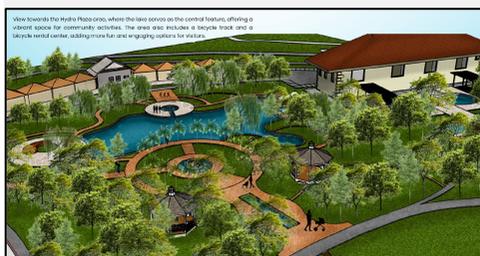


Figure 33: View towards Hydro Plaza



Figure 34: View towards Hydrothermal Sanctuary

## MASTER PLAN



Figure 35: Master plan

## SECTIONAL ELEVATIONS AND PERSPECTIVES

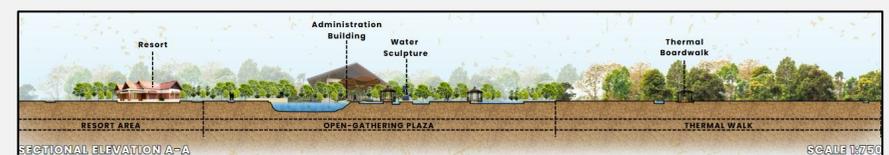


Figure 36: Sectional elevation A-A

Sectional elevation A-A shows spaces from the private resort area to public zones such as the gathering plaza and thermal walk. Key features include shaded trees, a mist bridge, water sculpture, and a man-made lake, all designed to create a relaxing, sensory-rich experience that blends privacy, community, and nature.

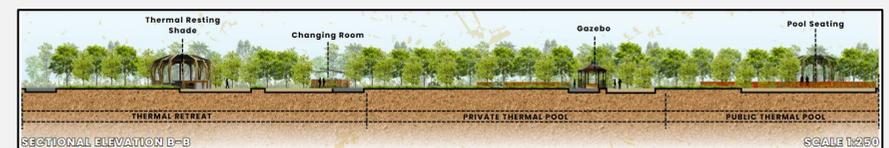


Figure 37: Sectional elevation B-B

Figure 37 shows section B-B of the Hydrothermal Sanctuary, highlighting the Thermal Retreat and Radiant Thermal zones. It features quiet rest areas and soaking pools that use geothermal water and natural moss for relaxation and skin therapy in a calm, natural setting.

## DETAILED DEVELOPMENT PLAN

The Hydrothermal Sanctuary is chosen as the main focus of the development plan. This area reflects the core identity of the proposed design and potential to be the main attraction at Felda Residence Hot Springs. Located at the heart of the site, it highlights the project's goals of healing and geothermal therapy. This area brings together key thermal features that support relaxation, recovery, sensory experiences, and cultural value for the community.



Figure 38: Location of Detail Development Plan

Figure 38 illustrates the selected zone for the detailed development plan, derived from the overall master plan of Felda Residence Hot Springs, Sungkai, Perak. This designated area highlights the sanctuary's vital role in promoting health and wellness through the use of natural hot springs. Figure 39 presents the proposed spaces designed to showcase a therapeutic landscape environment, suitable for healing and geothermal therapy activities. Figure 40 provides an aerial perspective of the Hydrothermal Sanctuary, capturing the overall layout and the key elements within the development.

The site has five main zones that work together to create a relaxing and healing experience using geothermal water. In the centre is the Central Plaza, an open space with a mist canopy that cools the area and helps people relax. Next to it is the Thermal Kinetic zone, where heated paths and soaking spots support movement and body therapy. The Neurothermal Haven at the entrance uses scented plants, textures, and calming sounds to create a peaceful space for the mind. The Radiant Thermal area has pools, gazebos, and moss that is good for the skin. The Thermal Retreat zone offers quiet, private spaces for deeper relaxation.



Figure 39: Detailed development plan



Figure 40: Aerial view of Hydrothermal Sanctuary

## SECTIONAL ELEVATIONS AND PERSPECTIVES

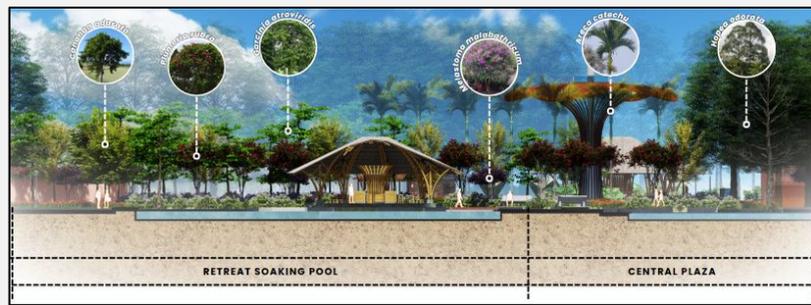


Figure 41: Sectional elevation C-C

Figure 41 shows sectional elevation C-C focuses on the Thermal Retreat area surrounded by sensory vegetation that supports mental relaxation through calming scents and colours.

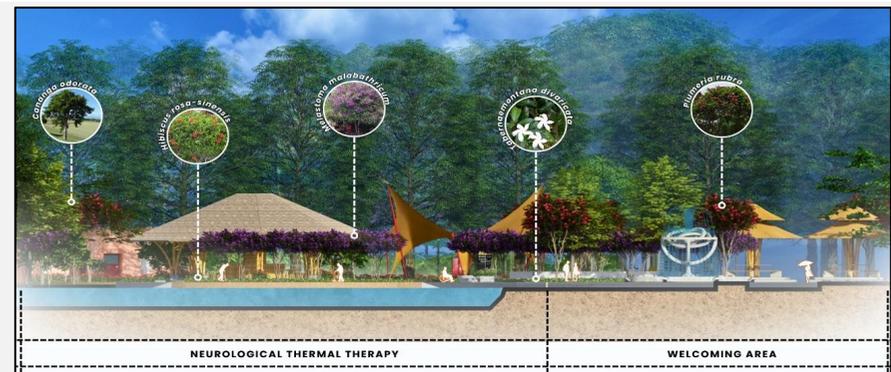


Figure 42: Sectional elevation D-D

Figure 42 shows sectional elevation D-D, which is at the Neurothermal Haven. This sectional elevation shows the area of neurological thermal therapy and welcoming area.



Figure 43: Aerial view of Thermal Retreat

Figure 43 shows the aerial view of the Thermal Retreat zone, offering a closer look at the spatial arrangement and tranquil atmosphere within this area of the Hydrothermal Sanctuary.



Figure 44: Aerial view of Neurothermal Haven

Figure 44 shows the aerial view of the Neurothermal Haven, a section of the Hydrothermal Sanctuary dedicated to neurological health and sensory treatment.

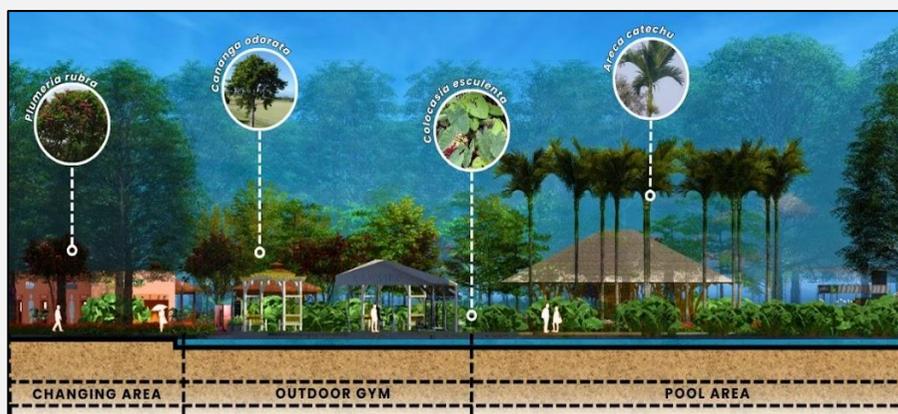


Figure 45: Sectional elevation E-E

Figure 45 shows the sectional elevation E-E, which is at the Thermal Kinetic shows the changing area and outdoor gym for the convenience of visitors.

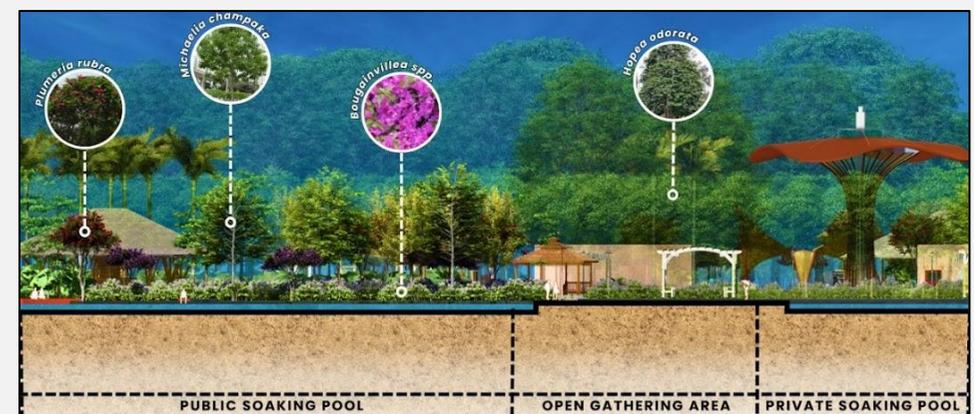


Figure 46: Sectional elevation F-F

Figure 46 shows the sectional elevation F-F at the Radiant Thermal shows the two types of soaking pools, private and public.

## SECTIONAL PERSPECTIVES AND EXTERIOR VIEWS

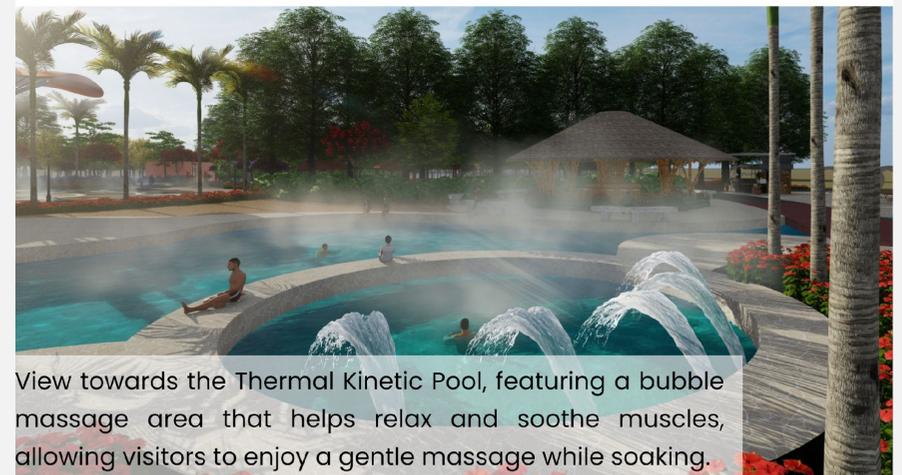


Figure 47: Perspective views



Figure 48: Sectional perspective

The Central Plaza (Figure 47) integrates mist-spraying technology that cools the surroundings, creating a refreshing microclimate for visitors after their hot spring activities. As the mist interacts with sunlight, it produces a rainbow-like effect, transforming the pavement into a visually captivating, Instagram-worthy feature. Beyond its aesthetic appeal, the plaza doubles as a relaxing, restorative resting area.

The Radiant Thermal Zone (Figure 48) emphasises the therapeutic mosses thoughtfully placed around the hot spring pools. Renowned for their natural skincare benefits—hydrating the skin, soothing inflammation, and offering a gentle touch—these mosses enrich both the visual character of the space and its wellness value. Their presence elevates the environment into a calming sanctuary that nurtures health, beauty, and overall well-being.

### Vaporine Spire

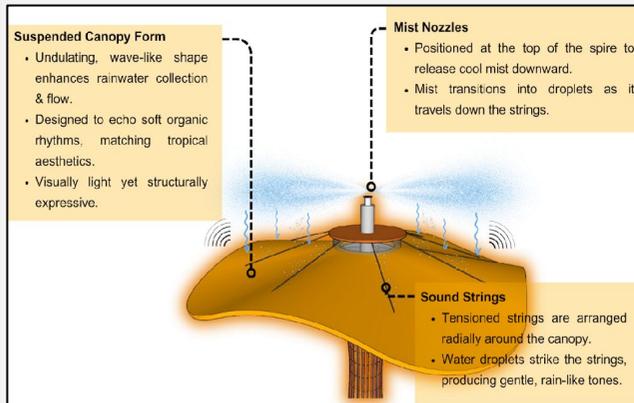


Figure 49: Sound string canopy

### INNOVATIVE DESIGN ELEMENT

Figure 49 shows the Vaporine Spire, located in the middle of the therapeutic hot spring landscape, is a trademark design piece that serves as both a cooling mist pavilion and the site's visual focal point. It improves tourists' experience by providing a relaxing, multimodal environment for individuals to unwind after hot spring activities. This structure combines geothermal cooling with sound and mist, increasing the site's therapeutic qualities while also providing a distinctive and picturesque environment. Last but not least, Figure 51 and 52 shows the overall softscape plan and hardscape for the selected detail development plan.

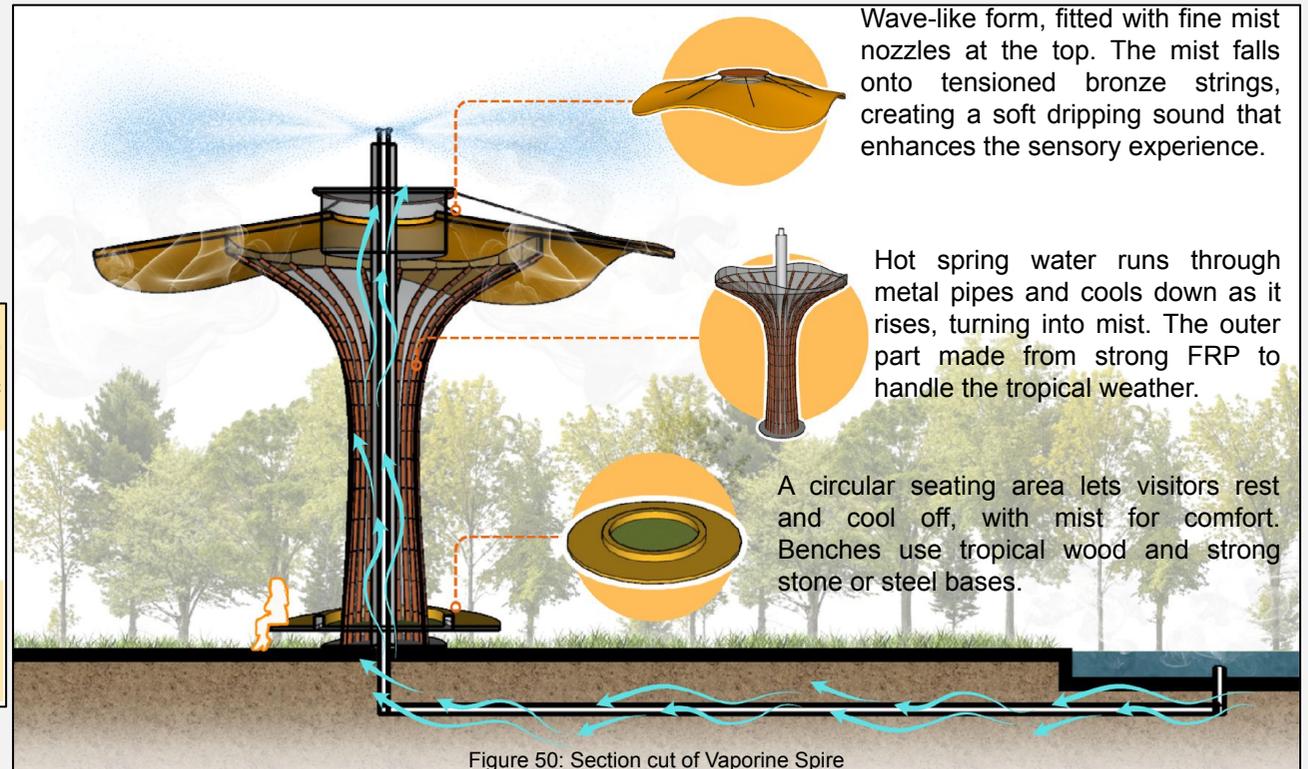


Figure 50: Section cut of Vaporine Spire

### SOFTSCAPE PLAN



Figure 51: Softscape plan

Table 2: Softscape schedule

SYMBOL	SCIENTIFIC NAME	COMMON NAME	NOS
	<i>Hopea odorata</i>	Merawan Siput Jantan	56
	<i>Cananga odorata</i>	Ylang-Ylang	63
	<i>Michelia champaka</i>	Cempaka	77
	<i>Cassia Fistula</i>	Golden Shower Tree	25
	<i>Plumeria rubra</i>	Red Frangipani	50
	<i>Garcinia atrovirens</i>	Asam Gelugur	33
	<i>Melastoma malabathricum</i>	Senduduk	78
	<i>Areca catechu</i>	Betel-Nut Palm	30
	<i>Hibiscus rosa-sinensis</i>	Chinese Hibiscus	1201
	<i>Colocasia esculenta</i>	Elephant Ear	108
	<i>Tabernaemontana divaricata</i>	Pinwheel	259
	<i>Ruellia tuberosa</i>	Minnie Root	473
	<i>Axonopus compressus</i>	Cow Grass	-

Tree   
 Palm   
 Shrub   
 Groundcover

### HARDSCAPE PLAN



Figure 52: Hardscape plan

Table 3: Hardscape schedule

SYMBOL	ITEM	MATERIAL DESCRIPTION	QTY
	Tennis	PVC-coated polypropylene fiberglass, or FRP film	1
	Gazebo	Timber, steel frame, polycarbonate roofing, thatch.	11
	Water Fountain	Reinforced concrete, natural stone (granite/marble), stainless steel	1
	Changing Room	Concrete block or prefab panels, aluminum doors, ventilation grille, mirrors	8
	Pergola Seating	Timber or powder-coated steel frame with polycarbonate or bamboo slats for roofing	5
	Outdoor Gym	Powder-coated steel frame, rubber or EPDM flooring for safety	1
	Deck	Wood (e.g., teak, mahogany), composite decking (WPC), or concrete with anti-slip coating	4
	Road	Asphalt, concrete.	5025m <sup>2</sup>
	Recreology Pavement	Pebbles or cobblestones embedded in concrete or mortar bed	177m <sup>2</sup>
	Piazza Pavement	Interlocking pavers, stamped concrete, or granite/slab tiles	189m <sup>2</sup>
	Pool Area Pavement	Anti-slip porcelain tiles, sandstone, travertine, or WPC decking	4885m <sup>2</sup>
	Changing Area Pavement	Ceramic or anti-slip porcelain tiles, concrete with surface treatment	10m <sup>2</sup>
	Welcoming Archway	Slab, wood	1
	Sand Pavement	Compacted sand layer, geotextile underneath for stability	1856m <sup>2</sup>
	Concrete Bench	Cast-in-place or precast concrete, with metal inserts	16
	Bridge	Reinforced concrete, timber deck, anti-slip surfacing	5
	Terracotta Pavement	Terracotta tiles or pavers laid on a compacted sub-base	127m <sup>2</sup>
	Kiosk	Aluminium frame, Wood-Plastic Composite (WPC)	2
	Hydro-mist structure	Cooled metal, bronze string, stainless steel pipe, FRP, frosted glass.	1
	Mist Pavement	Non-slip stone or concrete with integrated mist nozzles (brass/stainless steel)	123m <sup>2</sup>

### REFERENCES

Baloch, Q. B., Shah, S. N., Iqbal, N., Sheeraz, M., Asadullah, M., Mahar, S., & Khan, A. U. (2022). Impact of Tourism Development upon Environmental sustainability: a Suggested Framework for Sustainable Ecotourism. *Environmental Science and Pollution Research*, 30(3), 5917–5930. NCBI. <https://doi.org/10.1007/s11356-022-22496-w>

Barrick, K. A. (2007). Geyser Decline and Extinction in New Zealand—Energy Development Impacts and Implications for Environmental Management. *Environmental Management*, 39(6), 783–805. <https://doi.org/10.1007/s00267-005-0195-1>

Erfurt, P. (2021). The conservation of hot springs. In *Geoheritage, geoparks and geotourism* (pp. 91–118). [https://doi.org/10.1007/978-3-030-60463-9\\_4](https://doi.org/10.1007/978-3-030-60463-9_4)

Rosli, N. A., Anuar, M. N. A., Mansor, M. H., Abdul Rahim, N. S. I., & Arifin, M. H. (2022). What Makes A Hot Spring, Hot? *Warta Geologi*, 48(1), 30–35. <https://doi.org/10.7186/wg481202204>

Wang, W., & Lin, C. (2021). A model for Sustainable tourism development of hot spring destinations following poverty alleviation: Understanding the Tourists' perspective. *Sustainability*, 13(17), 9856. <https://doi.org/10.3390/su13179856>

Zhou, X., Zhuo, L., Wu, Y., Tao, G., Ma, J., Jiang, Z., Sui, L., Wang, Y., Wang, C., & Cui, J. (2023). Origin of some hot springs as conceptual geothermal models. *Journal of Hydrology*, 624, 129927. <https://doi.org/10.1016/j.jhydrol.2023.129927>