SINEKTIKA Jurnal Arsitektur

p-ISSN: 1411-8912
e-ISSN: 2714-6251
http://journals2.ums.ac.id/index.php/sinektika

IMPLEMENTATION OF GREEN SEA TURTLE ORGANISM LEVEL BIOMIMICRY PRINCIPLES IN SUSTAINABLE GLAMPING RESORT DESIGN

Aprilio Cardiola
Master's Degree Program of Architecture
Universitas Gunadarma
aprilio.cardiola21@gmail.com

Veronika Widi Prabawasari
Master's Degree Program of Architecture
Universitas Gunadarma
veronika@staff.gunadarma.ac.id

History of the manuscript:
Manuscript accepted December 5, 2025
Final manuscript accepted July 1, 2026

ABSTRACT

The increase in tourist accommodation needs, particularly in Tanjung Benoa, Bali, has led to the development of unique concepts such as glamping resorts. However, this development must address the crucial issue of Green Sea Turtle (*Chelonia mydas*) conservation, as Tanjung Benoa is a natural habitat for this endangered species. This research aims to solve the architectural design problem of a glamping resort in an environment with conservation issues by implementing the organism-level biomimicry approach on the Green Sea Turtle. This approach utilizes nature-tested solutions to develop a sustainable design. The study employs a design exploration method by substituting the five organism-level biomimicry variables (form, material, construction, process, and function) with the biological characteristics of the Green Sea Turtle. These variables are analyzed based on relevant architectural theories. The result shows a design concept for three glamping unit types that reflects the turtle's form and material composition, an elevated structure adapted from the turtle's skeleton, and spatial and utility planning that supports the turtle's life cycle and coastal ecosystem conservation. This design demonstrates that biomimicry principles provide sustainable tourism solutions by integrating five organism-level variables into technical architectural elements that minimize habitat disruption, preserve nesting grounds, and synchronize the resort's operational cycles with the natural ecosystem of the Green Sea Turtle.

KEYWORDS: glamping resort, green sea turtle, organism-level biomimicry, sustainable architecture, Tanjung Benoa

Peningkatan upaya pembangunan akomodasi hotel resort di Tanjung Benoa, Bali, mengikuti kenaikan okupansi yang cukup signifikan. Perkembangan ini menghadirkan tantangan utama terkait konservasi Penyu Hijau (Chelonia mydas), yang merupakan habitat alami di kawasan pesisir Tanjung Benoa. Penelitian ini bertujuan untuk memecahkan permasalahan perancangan arsitektur glamping resort di lingkungan dengan isu konservasi melalui implementasi pendekatan biomimikri tingkat organisme terhadap Penyu Hijau. Metode yang digunakan adalah eksplorasi desain dengan mensubstitusi lima variabel biomimikri tingkat organisme (bentuk, material, konstruksi, proses, dan fungsi) dengan karakteristik biologis Penyu Hijau, yang kemudian dianalisis berdasarkan teori arsitektur yang relevan. Hasil penelitian ini berupa konsep desain tiga tipe unit glamping yang mengadaptasi bentuk dan komposisi material penyu, sistem struktur panggung yang meniru kerangka penyu, serta perencanaan ruang dan utilitas yang mendukung daur hidup penyu dan konservasi ekosistem pesisir. Desain ini menunjukkan bahwa prinsip biomimikri memberikan solusi pariwisata berkelanjutan dengan mengintegrasikan lima variabel tingkat organisme ke dalam elemen teknis arsitektural yang meminimalkan gangguan habitat, melestarikan area bertelur, dan menyelaraskan siklus operasional resor dengan ekosistem alami Penyu Hijau.

KATA KUNCI: *glamping resort, penyu hijau, biomimikri tingkat organisme, arsitektur berkelanjutan, Tanjung Benoa*

INTRODUCTION

The rise in Bali's accommodation occupancy rate, recording a 30.2 percent increase year-on-year in Q4/2022, has driven efforts to develop hotel resorts, particularly in Tanjung Benoa (Nurdifa, 2023). Glamping, a type of nomadic tourism combining luxury and nature, is gaining popularity in Bali, found in areas like Kintamani, Ubud, and Tabanan. Glamping is defined as a form of camping that exceeds the comfort and luxury levels of traditional camping (Milohnić et al., 2019). Tanjung Benoa, with its high demand for tourist accommodation, presents a good potential for glamping resort development. However, the coastal area of Tanjung Benoa is also a natural habitat for the Green Sea Turtle (*Chelonia mydas*), an endangered species facing population decline due to overexploitation and habitat loss caused by non-environmentally friendly tourism projects (Budiman, 2022)

The main problem addressed in this study is the planning and design of an architectural object (Glamping Resort) in the natural habitat of the Green Sea Turtle. The resort design must support the increasing tourism needs while addressing the urgent issue of turtle conservation and the coastal environment. Therefore, this research aims to solve this design challenge through an ecological approach, specifically *biomimicry*, which focuses on imitating nature to achieve sustainability and prevent species extinction (Bianciardi et al., 2017).

Organism-Level Biomimicry as an Architectural Approach

Biomimicry is defined as imitating or mimicking nature, allowing the implementation of natural systems in design to solve human problems. This method can create ecologically standardized innovations through the adaptation of natural objects like animals or plants (Zari, 2018). Biomimicry can be categorized into three levels: organism, behavior, and ecosystem. This study specifically focuses on the organism level (Amer, 2019). The framework for applying organism-level biomimicry in architecture involves five core variables: form, material, construction, process, and function.

- Form in biomimetic architecture means the building visually resembles the organism being mimicked. In architectural terms, form includes basic shape (circle, square, triangle), size/ratio, color, and texture (Ching, 2015).
- Material implies the building is constructed using the same type of material or a material that mimics the chemical composition of the organism's components.
- Construction means the building is constructed in the same manner as the organism is formed, such as imitating the organism's growth cycles or skeletal structure.
- Process dictates that the building must operate similarly to the individual organism, for instance, a building mimicking an oxygen-producing plant must also be designed to produce oxygen.
- Function refers to the building's role reflecting the organism's function in a broader context, particularly in relation to the environment and users.

Green Sea Turtle (*Chelonia mydas*) as the Subject

The Green Sea Turtle (*Chelonia mydas*) is one of the sea turtle species found in Indonesian waters. The International Union for Conservation of Nature (IUCN) lists the green turtle on the Red List of Threatened Species because its population is declining. This decline is due to vulnerable life cycles and unfriendly human activities. Damage to nesting habitats can reduce the survival of the green turtle itself (Maisyaroh & Andriyono, 2014). The green turtle is a protected animal under Indonesian Law No. 5 of 1990 and PP No. 7 of 1999. The key morphological and biological characteristics relevant for the organism-level biomimicry approach are:

- Form: The body is generally flat when mature; the carapace is oval-shaped (Isdianto et al., 2022). The head is small and rounded, approximately 15 cm wide. The carapace scales are thin, smooth, and flexible. Morphologically, the carapace features five scutes in the middle, four pairs of lateral scales, and usually twelve pairs of marginal scales. The average Carapace Length (CCL) is 86.9 ± 6.14 cm, and the Carapace Width (CCW) is 77.9 ± 5.95 cm.

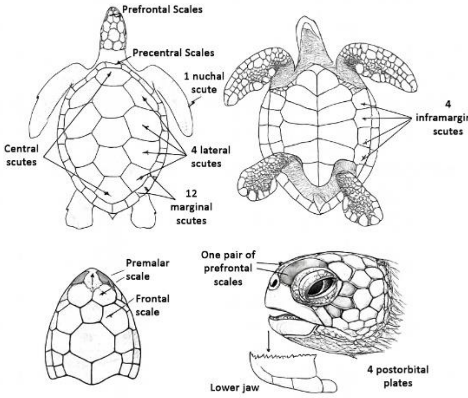


Figure 1. Green turtle morphology
(Source: Tomascik et al., 1997)

- Material: The shell largely consists of an organic matrix rich in keratin and collagen. The inorganic components include calcium phosphate and calcium sulfate. This unique combination of materials provides the shell with both strength and flexibility (Chen et al., 2017).

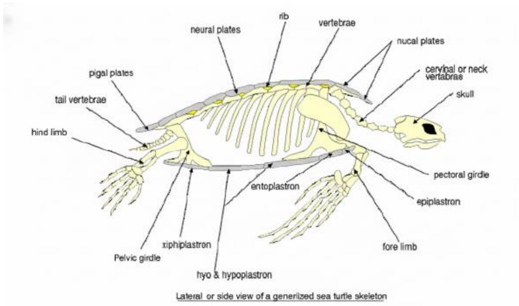


Figure 2. Green turtle skeleton
(Source: Hirasawa et al., 2013)

- Construction: The skeleton forms a protective box around the soft body tissues. The carapace is formed from costal and neural bone plates connected to the ribs and spine(Hirasawa et al., 2013). The endoskeleton is bony, and the ribs, spine, pectoral girdle, and pelvic girdle are fused with the inner layer of the exoskeleton. The forelimbs are specially adapted for swimming, shaped like paddles.

- Process: Green turtles migrate long distances between feeding and nesting sites. They spend about 90–95% of their lives at sea, while only 5–10% is spent on land for nesting and hatching. Successful nesting requires components such as sandy beaches, easy access for hatchlings, and appropriate incubation temperatures (Isdianto et al., 2022). Nest temperature, particularly above 30 °C, determines the sex of the hatchlings.
- Function: The external function is critical for maintaining the shallow water ecosystem. Green turtles help improve the health and growth of seagrass beds by eating only the top part of the grass. At nesting beaches, they provide essential nutrients to the ecosystem through their hatched eggshells. Their streamlined body shape reduces drag in the water, which aids swimming and health.

This research aims to implement the organism-level biomimicry approach on the Chelonia mydas and explore the resulting architectural form design for a Glamping Resort.

METHODS

This study employs a qualitative method, utilizing design exploration as the primary analytical tool. The methodology follows a systematic design process, where the biomimicry framework is applied to derive architectural concepts (Cross, 2011).

The main analysis method is design exploration, adapting the organism-level biomimicry framework (Zari, 2018). According to Nigel Cross, design exploration is an essential part of the design process that involves several iterative stages. Cross explains that design exploration encompasses creative, investigative, and reflective activities that help designers understand the problem more deeply and generate innovative solutions. There are 2 (two) main stages in the design exploration analysis process, which are:

1. **Variable Analysis:** Substituting the five organism-level biomimicry variables (Form, Material, Construction, Process, Function) with the characteristics of the Green Sea Turtle. These characteristics are then interpreted and translated into relevant architectural parameters (Table 1).

Table 1. Biomimicry Architecture Framework Analysis

Variable	Sub Variable	Analysis of variables on the Green Sea Turtle
Form	Basic Form	Analysis of the Green Sea Turtle's Basic Shape
	Size (carapace) pxl (rasio) p : 1)	Analysis of the Green Sea Turtle's Size / Ratio
	Color (Primary, Secondary, Tertiary, Neutral)	Analysis of the Green Sea Turtle's Color
	Surface Texture (Rough-smooth, Hard-soft)	Analysis of the Green Sea Turtle's Texture
Material	Organic	Analysis of the Green Sea Turtle's Organic Material
	Inorganic	Analysis of the Green Sea Turtle's Inorganic Material
Cons-truction	Upper Structure	Analysis of the Green Sea Turtle's Upper Structure
	Middle Structure	Analysis of the Green Sea Turtle's Middle Structure
	Lower Structure	Analysis of the Green Sea Turtle's Lower Structure
Process	Life Cycle	Analysis of the Green Sea Turtle's Life Cycle
	Habitat	Analysis of the Green Sea Turtle's Habitat
Function	External	Analysis of the Green Sea Turtle's External Function
	Internal	Analysis of the Green Sea Turtle's Internal Function

2. **Form Exploration Stages**: The results from the variable analysis are used as inputs for a five-stage form exploration process to generate the final design variations (Figure 3).

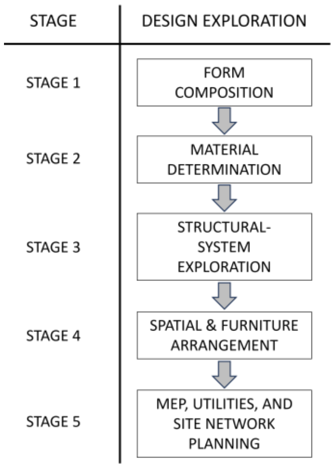


Figure 3. Stage of Design Exploration
(Source: Author's Document, 2025)

- Stage 1: Form Composition: Combining or subtracting the basic shapes, ratio, color, and texture of the turtle (Ching, 2015).
- Stage 2: Material Determination: Elaborating the design by selecting organic and inorganic materials that mimic the turtle's biological composition.
- Stage 3: Structural System Exploration: Applying the construction principles derived from the turtle's skeleton and incorporating site-specific data and capacity requirements

(Ching, 2014).

- Stage 4: Spatial Planning and Furniture: Designing the program space, circulation, and interior layout based on the turtle's life cycle process and comparison with similar glamping projects.
- Stage 5: ME, Utilities, and Site Planning: Integrating the external and internal functions of the turtle (e.g., streamlined form, waste system) into the site plan and utility systems (plumbing, solar panels).

The results of this design exploration are then evaluated against the established parameters to ensure the architectural design successfully implements the biomimicry concept, which supports the function of the Glamping Resort and the conservation goals for the green sea turtle.

RESULTS AND DISCUSSION

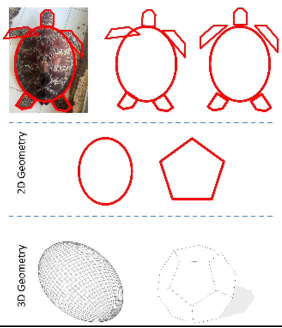
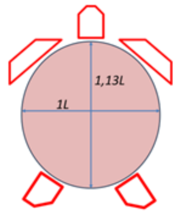
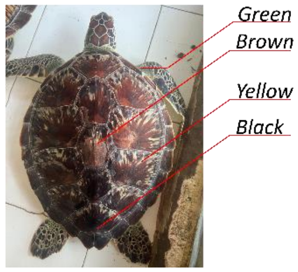
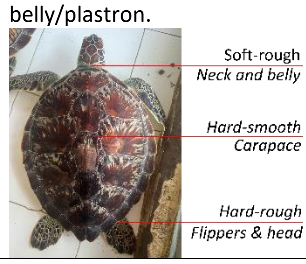
The Glamping Resort is planned for Nusa Pudut, Tanjung Benoa, Bali. Following the data from similar projects, three types of glamping units were determined to meet capacity and location needs: Family Type (4-6 people), Standard Beach Type (2-3 people), and Offshore Type (2-3 people) (Craig & Karabas, 2021).The design process involved applying the organism-level biomimicry framework as follows:

Analysis of Biomimicry Variables

Form Variable Analysis

The turtle's form is characterized by two dominant basic shapes: the circle/oval (2D) and the pentagon (2D). The turtle's carapace has a length-to-width ratio of approximately 1.13:1 (average 89 cm/79 cm) (Maisyaroh & Andriyono, 2014). The color palette derived from the turtle includes Green (Secondary), Brown (Tertiary), Yellow (Primary), and Black/White (Neutral). The texture varies: the carapace is hard and smooth, the head/limbs are hard and rough, and the neck/belly is soft and smooth/rough (Table 2).

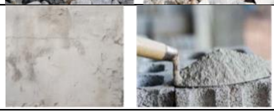
Table 2. Form Variable Analysis

Variable	Sub Variable	Variable Analysis of the Green Sea Turtle
Form	Basic Shape	Circle/oval, and pentagon 
	Size (carapace) (l x w) (ratio) l : w	L x W (Length x Width) with an L:W ratio of (1.13:1) 
	Color (Primary, Secondary, Tertiary, Neutral)	Primery : Yellow, Secondary : Green, Tertiary : Brown, Neutral : Black.  
	Surface Texture (Rough-smooth, Hard-soft)	Hard and smooth on the carapace, Hard and rough on the skin surface of the head and limbs/flippers. Smooth and soft on the neck and belly/plastron. 

Material Variable Analysis

The organic components of the turtle's skeleton are collagen and keratin. Architectural materials derived from these include Keratin-Cellulose Composites, Keratin-Filled Concrete, Collagen-Cement Composites, Keratin-Based Bioplastics, Keratin Foam, and Keratin Composite Roofing (Chen et al., 2017). The inorganic components are Calcium Carbonate and Calcium Phosphate (Table 3). These correspond to traditional building materials like aggregate, limestone, cement, concrete, plaster, wall paint, and gypsum. The resulting massing is a combination of these elements.

Table 3. Analysis of the Green Sea Turtle's Material

Variable	Material	Analysis of the Green Sea Turtle's
Organic Material	Keratin-Cellulose Composites	
	Keratin-Filled Concrete	
	Keratin-Based Bioplastics	
Inorganic Material	Calcium Carbonate	
	Calcium Phosphate	

Construction Variable Analysis

The turtle's skeleton is a source of construction inspiration. The carapace, which is fused with the spine, represents the integrated roof and frame structure (Ching, 2014). The pelvic and pectoral girdles (pelvis and shoulder bones), which connect the carapace and plastron, are translated into columns or structural elements that create a column-free central space. The plastron (lower shell) and limbs suggest a suspended floor (platform) and foundation system (pilings), creating a crawl space between the floor and the ground.

Table 4. Construction Variable Analysis

Sub Variable	Analysis of the Green Sea Turtle's
Upper Structure	Carapace, directly connected to the spine.
Middle Structure	Pectoral girdle and pelvic girdle
Lower Structure	Plastron and limbs

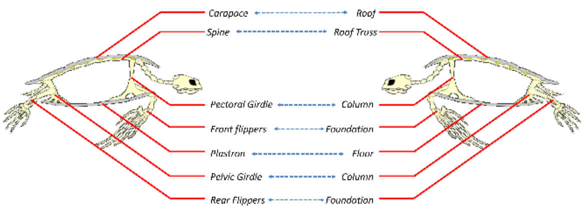


Figure 4. Illustration of construction variable analysis (Source: Author's Document, 2025)

Process Variable Analysis

The turtle's life cycle dictates the required spatial program (Isdianto et al., 2022)

- Nesting: Requires a private sandy beach area (Nesting Area). This is translated into a Terrace/Foyer (Arrival) space for the glamping unit.
- Growing up: Requires feeding grounds like seagrass, coral reefs, and mangroves. This translates to Pantry/Kitchen and Bathroom (Eating & Excretion).
- Migration: Requires the open sea. This is translated into the Living Room/Main Social Area.
- Mating: Occurs in coastal areas. This is translated into the Bedroom/Main Rest Area.

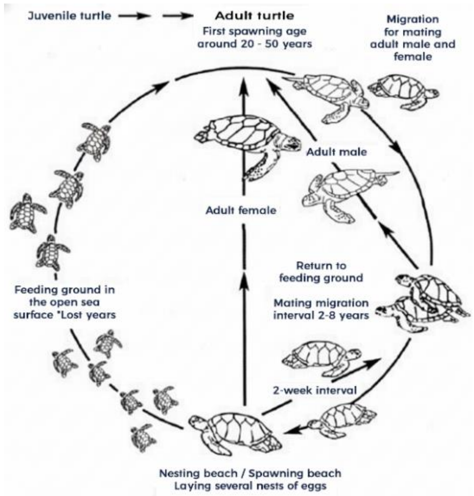


Figure 5. Life cycle of the Green Sea Turtle (Source: Author's Document, 2025)

Table 5. Process Variable Analysis on Spatial Requirements

Process	Spatial needs
Nesting	Nesting Area
Growth to maturity	Seagrass beds, coral reefs, and mangroves
Migration	Direct beach access to the sea
mating	Beach sand

The time distribution of the turtle's life (90-95% at sea, 5-10% on land) is used to determine the hierarchy of space: a 1:9 ratio for land to water area in facilities like the swimming pool or as an elevation difference to define spatial boundaries.

Function Variable Analysis

External Function (Ecosystem Contribution): Just as the green turtle functions as a keystone species that maintains seagrass health and enriches coastal habitats, the building design mimics this symbiotic role by actively supporting the ecosystem (Darmarani et al., 2020). This is achieved through an Elevated Structure to minimize physical impact on the nesting sand, an environmentally friendly drainage concept and a nursery for coastal vegetation, reflecting the turtle's natural contribution to maintaining its environment (Zari, 2018).

Internal Function (Body Efficiency): The turtle's streamlined shape and efficient excretory system inspire the building's utility design. This translates to energy efficiency (e.g., solar panels) and a plumbing design with a filtration system to avoid direct untreated waste discharge.

Form Exploration Stages

The analysis results are then systematically implemented in the five-stage exploration process.

Stage 1: Form Composition

The initial design is based on the turtle's oval/pentagon shape with the 1:1,13 ratio. This abstract form is the basis for the subsequent three glamping types, utilizing both additive (e.g., combining shell and head forms) and subtractive (e.g., creating openings) transformations (Ching, 2015).

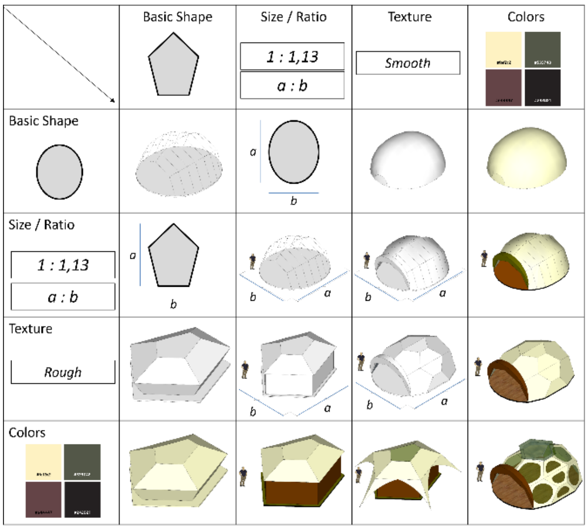
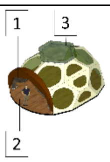
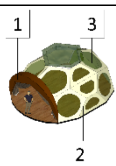


Figure 6. Stage 1, Form Composition
(Source: Author's Document, 2025)

Stage 2: Material Determination

The form from Stage 1 is detailed with the selected biomimetic materials. The design is elaborated using concrete and plaster (inorganic components) and natural fibers/keratin composites for secondary skin or insulation (organic components). This resulted in an abstract, shell-like form that utilizes a combination of flat concrete (representing the inorganic shell) and keratin/wool fabric as insulating or facade elements.

Table 6. Stage 2, Analysis of material determination

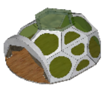
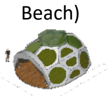
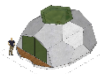
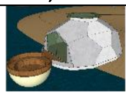
Exploration Result - Stage 1	Idea for determining organic material	Idea for determining inorganic material	Design elaboration
	 1 3 2 1. Wool fabric 2. Composite + Ceratine 3. Resin + Ceratine	 1 3 2 1.Concrete Plester 2.Shell Structure 3.Concrete + Ceratine	

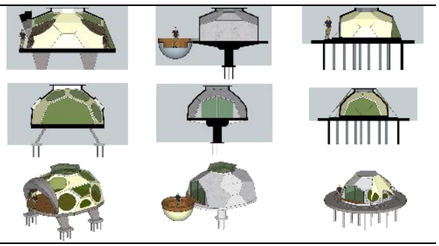
Stage 3: Structural System Exploration

The design is adapted to the three glamping types (Family, Standard, Offshore) based on their required areas and site conditions, strictly applying the turtle's construction principles: integrated roof and frame, column-free central space, and elevated structure with a crawl space (Ching, 2014).

- **Family Type (40 m2)**: Features an elevated **structure** with reinforced concrete columns, a view orientation towards the open sea, and is located near the mangrove area.
- **Standard Type (25 m2):** Uses a semi-offshore elevated structure with centralized structural columns and a cantilevered deck/balak, including a floating terrace.
- **Offshore Type (20 m2):** Uses an offshore structure with reinforced concrete piles/pipes and is connected by a deck. This type is also equipped with a secondary tent skin to block excessive sunlight.

Table 7. Stage 3, Structural System Analysis

Shape exploration result Stage 2	Family Type	Standard Type	Offshore Type
 **1 : 1,13**	40m2 (ref : Bali Beach)  **6 : 6,8**	25m2 (ref : Kubah Bali & Bali Beach)  **4,5 : 5**	20m2 (ref: Kubah Bali)  **4,2 : 4,75**
Site Planning Aspect Developmen t	 (Seashore with mangrove)	 (Seashore)	 (Offshore)
Description	▪ Elevated Structure with reinforced concrete columns ▪ Design with view Orientation ▪ Opening towards the offshore/ open sea	▪ Elevated Structure with a centralized structural column and cantilever beam ▪ Semi-Offshore Design with floating deck/ ▪ terrace	▪ Offshore structure with reinforced concrete pipes ▪ Exclusive design offshore connected with a deck ▪ Secondary skin tends to block excessive sunlight during the day

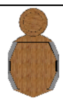
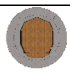
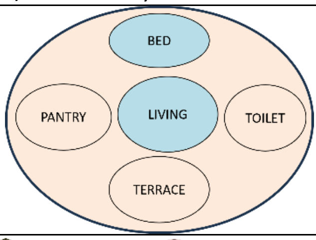
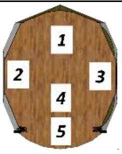
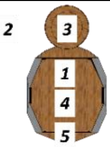
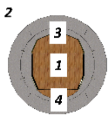
Structural Design / Structural Scheme	

Stage 4: Spatial Planning and Furniture

The spatial needs derived from the turtle's life cycle are integrated with the floor plans of the three glamping types. The Standard and Offshore types simplify the internal program by placing the bathroom outside the main unit, as seen in the comparison with the Kubah Bali Glamping Resort.

- Family Type: Contains a Foyer (Arrival), Living Room (Social/Migration), Bedroom (Rest/Mating), Pantry/Kitchen (Eating), and an indoor bathroom.
- Standard Type: Features a smaller layout including a Transition Area (Arrival), Bedroom (Rest/Mating), and a floating open deck/terrace (Arrival/Mating), with a separate external bathroom.
- Offshore Type: The most compact unit, including a Transition Area (Arrival) and Bedroom (Rest/Mating), with a separate external bathroom.

Table 8. Stage 4 : Analysis of Spatial Planning and Furniture

	Capacity 4-6 (family type)	**Capacity 2-3 (standard type)**	**Capacity 2-3 (offshore type)**
Shape exploration result Stage 3	40 m2 	25 m2 	20 m2 
Shape and size layout	 6 : 6,8	 4,5 : 5	 4,2 : 4,75
Process variable analysis results			
Elaboration Results	 1. Bed 2. Toilet 3. Living 4. Pantry 5. Terrace	 1. Bed 2. Toilet (outside) 3. Living 4. Pantry 5. Terrace	 1. Bed 2. Toilet (outside) 3. Pantry 4. Terrace

Stage 5: ME, Utilities, and Site Planning

The site plan is developed based on the external function (conservation) and the internal function (efficiency) analyses. The site is divided into five main zones (Darmarani et al., 2020)

- Zone A (Main Entrance/Public): Drop-off, Reception, Jetty, Information Center, Mosque/Toilet.
- Zone B (Management/Service): Management Office, Service Utility, Storage, Back-end Kitchen.
- Zone C (Glamping Units): Glamping Units (CS - Sectoral Glamping Unit).
- Zone D (Supporting Facilities): Turtle Center & Hatchery (D1), Restaurant/Souvenir Shop (D2).
- Zone E (Conservation Zone): Turtle Hatchery Area (E1), Turtle Pool & Tank (E2), Mangrove Buffer (E3), Conservation Beach (E4), Interpretive Path (E5), and Conservation Post (E6).

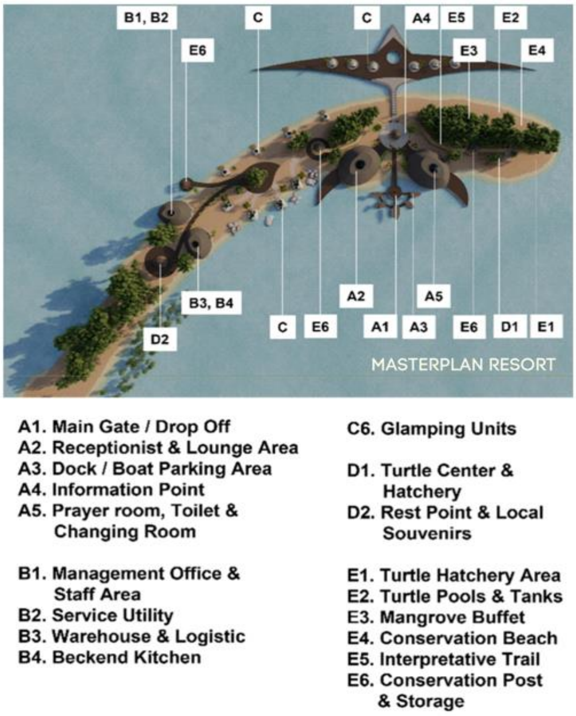


Figure 7. Site Plan
(Source: Author's Document, 2025)

Conservation principles are applied by establishing a clear Conservation Zone (E), which includes the nesting beach and mangrove buffer, separated from the main public and accommodation areas. The use of an elevated structure across the glamping units in Zone C minimizes impact on the terrain. Utility planning incorporates solar panels for energy efficiency and a wastewater system with a filtration design to protect the coastal environment from direct pollution, mimicking the turtle's efficient excretory system (Zari, 2018).

The implementation of these biomimetic variables extends beyond the physical building envelope; it fundamentally dictates the ecological performance of the resort. By adopting the turtle's skeletal framework into an elevated stilt structure across all glamping units, the design successfully minimizes soil compaction, preserving the natural sandy beach required for turtle nesting. Furthermore, the integration of the turtle's efficient internal processing into the site's utility planning, specifically through a decentralized, filtered wastewater system, prevents direct effluent discharge into the sea, thereby protecting the delicate seagrass beds.

CONCLUSION

This research successfully achieved its goal of implementing the organism-level biomimicry approach on the Green Sea Turtle (*Chelonia mydas*) to develop a sustainable design for a Glamping Resort in a coastal conservation area. The design exploration methodology systematically translated the turtle's biological characteristics into architectural parameters across five variables (form, material, construction, process, and function)

The resulting design comprises three glamping unit types (Family, Standard, Offshore) with massing and layout that abstractly reflect the turtle's oval/pentagonal shape and 1.13:1 ratio. Construction utilizes the principle of the turtle's skeleton, featuring an elevated structure with an integrated shell-like roof (carapace) and column system (girdles). Material selection prioritizes mimicking the turtle's keratin, collagen, and calcium components using sustainable alternatives such as Keratin-Cellulose Composites and concrete/plaster. Furthermore, the design incorporates spatial planning that supports the turtle's life cycle (e.g., dedicated nesting area, Living/Bedroom) and environmentally-friendly utilities (solar panels, filtered drainage), which reflects its process and function in the ecosystem. This demonstrates that by extending biomimetic principles beyond the physical building envelope into site integration and operational systems (such as minimizing the structural footprint to protect nesting sands and filtering utility waste to preserve seagrass), tourism architecture can actively support the conservation of protected organisms and their habitat.

Further research should focus on the technical details, such as structural analysis, material testing for the bio-composites, energy performance simulations, and economic feasibility analysis to ensure the design's practicality and real-world application.

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