Biomimetic Architecture: Case Studies of the Gherkin Tower and the Eastgate Center

1. Biomimetic Architecture

Sustainable design is gaining importance as demands on the world’s resources increase. One solution that architects are increasingly looking towards is nature. Nature provides an exemplary model of sustainable design, as organisms in nature adroitly adapt to environmental changes, rely on readily available, local sources of energy, and are non-toxic and self-sustaining [1]. Nature-inspired design can manifest in various ways. For example, buildings can assume forms that mimic nature, be constructed out of novel, sustainable materials, or be engineered to replicate the functions of nature [2]. The Gherkin Tower in London, which resembles the Venus flower basket sea sponge and the Eastgate Center in Harare, Zimbabwe, modeled after termite mounds, are compelling examples of modern architecture that have drawn inspiration from nature to realize improved structural stability and reduced energy consumption. In exploring these two cases, the paper will examine the unique features of the organisms that serve as the inspiration, and then analyze how those features have been incorporated into the form, material selection, and functionality of the buildings.

2. The Gherkin Tower and the Venus Sea Sponge

The Gherkin Tower, a 40-story office building located in the center of London at 30 St. Mary Axe, was designed by Foster & Associates in 2003 for the insurance company Swiss Re. The
goal was to create an environmentally progressive building that fostered a highly functional internal working environment while also interacting in a complimentary manner with its external surroundings. To this end, a number of specific design criteria had to be satisfied, including “enhancement of the public environment at street level, flexibly serviced, ‘user-friendly’ office spaces, good interconnectivity between floors, minimum impact on the local wind environment, and reduced energy consumption through use of natural ventilation” [3]. The product was a unique building with a diagrid lattice of steel and glass, spiraling floors, and a tapering cylindrical form conducive to natural ventilation [4]. Due to these features, the building draws numerous comparisons to the Venus flower basket sea sponge (genus: *Euplectella*) (Fig. 1) [5,6].

![Fig. 1. Inspiration for Gherkin Tower. The Venus sea sponge and the Gherkin Tower both possess a structurally stable exoskeleton/lattice and exhibit effective ventilation.](image)

**Exoskeleton/Lattice**

The Venus sea sponge has a multi-hierarchical exoskeleton cage made mostly of silica, the main component of glass. Although silica is a brittle material, each hierarchical level is organized to interact with each other in an intricate, bottom-up manner, resulting in an overall strong and tough scaffolding structure (Fig. 2) [7,8]. At the nano/micro-level, hydrated silica nanoparticles of 50-200 nm in diameter are deposited around a protein filament to form the fundamental
construction layer [9]. These layers are then concentrically arranged on top of each other to form rod-like spicules. The spicules function as lamellar composites comprised of alternating stiff inorganic layers and flexible organic layers, with the inorganic layers providing rigidity, and the organic layers reducing crack propagation [8]. The spicules are joined into parallel bundles to provide defect tolerance and strength. The bundles are then arranged into a square lattice that wraps around to form the cylindrical exoskeleton cage of the Venus sea sponge. The cage is reinforced by diagonal fibers acting as struts. Finally, the entire cage is coated with a cement-like silica matrix that joins the fibers at their nodes and holds the various components together [9].

![Image](image.png)

**Fig. 2. Multi-hierarchical structure of Venus sea sponge.** The exoskeleton cage of the sea sponge is comprised of silica spicules, which comprise the square lattice enclosed in a matrix.

The external lattice of the Gherkin Tower shows striking resemblance to the exoskeleton cage of the Venus sea sponge, both in terms of its hierarchical structure and material composition. The Tower is comprised of a core of solid steel beams and an external lattice of aluminum-coated steel unto which double-panned, argon-reinforced glass panels are placed (Fig. 3). Steel provides structural strength and rigidity, while the transparency of the glass maximizes inflow of natural light and gives the building a sleek, modern appearance [3]. The steel frames and glass panes are arranged in a diagrid lattice with nodes at its connecting points (Appendix Fig. A1), analogous to how the Venus sea sponge is comprised of a silica lattice reinforced with
diagonal fiber struts. The diagrid lattice, which consists of triangular “grids” with “diagonal” supports, is significant because it provides improved stability against various loads. Vertical/gravity loads are evenly dispersed into the lower diagonal members, while effects of horizontal/shear loads are minimized due to the rigid triangular arrangement. Furthermore, lateral loads are distributed in two directions, “windward” (extending up to the apex) and “leeward” (extending down to the lower members). Reducing lateral stresses in this manner is particularly important, given the tall height of the building [10]. Hexagonal nodes, welded together at the intersection of the diagrids, rigidly connect the members and divide loading along a greater number of directions [3], thereby functioning similarly to the cement-like silica matrix of the Venus sea sponge.

In addition to structural stability, the diagrid lattice also enhances sustainability. Unlike conventional high-rise structures, diagrids have no need for vertical columns around their perimeters, as the rigidity and strength of the diagrid structure itself is sufficient in keeping the building upright. As a result, diagrid lattices require approximately 20% less steel than conventional steel frames, yielding significant economic and environmental benefits [11].

Fig. 3. Steel and glass lattice of Gherkin Tower. Steel frames serve as the support, unto which glass panes are positioned. Both are arranged in a diagrid lattice to provide structural stability.
Spiraling Structure

Another similarity between the Venus sea sponge and the Gherkin Tower is in their spiraling structures. The cylindrical cage of the sea sponge is encircled by a helical silica ridge that further supports the structure [8]. Specifically, the ridge increases bending stability, thereby preventing ovalization and enabling retention of the cylindrical form. The ridges are particularly concentrated towards the middle of the sea sponge, where its structure bulges slightly. The ridges also exhibit high density towards the top, providing additional support to account for increasing instability with height [9]. In the Gherkin Tower, the helical ridges are paralleled by spiraling floors, where each floor is rotated in relation to the one below it using radial beams on 10° centerlines. This slightly staggered arrangement stabilizes the 40-story building, allowing it to assume its bulging, tapering shape. This rotated arrangement also enables the incorporation of vertical lightwells that maximize inflow of natural light. Furthermore, it accommodates more open, flexible space in between the floors, enhancing functional utility [3].

Flow and Natural Ventilation

The cylindrical shape of the Venus sea sponge allows water currents to pass more easily around it, reducing impact with their full force. Furthermore, the mesh-like silica lattice facilitates localized circulation, allowing efficient filtration of nutrients [12]. In a similar manner, the Gherkin Tower relies on its curving, aerodynamic form to help wind flow more smoothly around the building [13]. The slight bulge towards the middle of the tower reduces wind flow at the slimmer base, preventing strong currents from reflecting off the building’s surface onto pedestrians on the public ground floor level (Appendix Fig. A2). The smoother wind flow also reduces surface heat loss and facilitates natural ventilation [14].
The unique double skin façade windows of the Gherkin Tower further facilitate natural ventilation in a manner similar to the Venus sea sponge’s filtration mechanism. The outer, double-glazed solar control glass window is separated from the inner glass window by an approximately 1.5m wide cavity [13]. The open cavity assists with air circulation and heat extraction, while the double-glazed façade provides acoustic and thermal insulation [15]. The façade design is further enhanced through an integrated system of sensors and operable blinds. Sensors on the exterior of the building monitor temperature, wind speed, and level of sunlight, and based on this information, blinds located inside the cavity are opened and closed accordingly [13]. The result is that the Gherkin Tower is able to reduce air-conditioning use by 50% compared to conventional high-rise buildings, realizing significant energy savings [13, 15].

3. The Eastgate Center and Termite Mounds

The Eastgate Center is a shopping center and office complex located in Harare, Zimbabwe’s capital. It was designed by architect Mike Pearce in collaboration with the Arup Group, with construction completed in 1996 [16]. In line with his philosophy of “tropical architecture,” Pearce considered two primary criteria in designing the complex. First, he wanted the building to be well-suited to the hot, tropical climate of Zimbabwe, and second, he wished to draw upon inspiration from local nature [17]. With this motivation, he turned his attention to mound-building termites (*Macrotermes michaelseni*), commonly found in the tropical savannas of Africa (Fig. 4) [18,19]. As their name suggests, these termites are notable for constructing massive (approximately 4m in height) mounds that comprise a complex ventilation system above their central underground nest/colony [16]. Similarly, the Eastgate Center consists of tall chimney
stacks, has many ventilation openings, and is constructed out of high-thermal capacity materials, all which contribute to enable energy-efficient temperature control [17].

![Image](image1.png)

**Fig. 4. Inspiration for Eastgate Center.** The mounds constructed by *M. michaelseni* termites served as the inspiration for the Eastgate Center, particularly in regards to thermal regulation.

**The Engineering of Termite Mounds**

The mounds constructed by *M. michaelseni* comprise one component of an extremely complex and intricate thermal regulation system. The system consists of the subterranean nests and cellars in which the termites live, above which lie a series of conduits, channels, and chimneys that permeate the mounds (Fig. 5a). Many of these features extend high above ground, interacting with the external environment. Due to this structure, three different heat zones arise at different levels of the mound (Fig. 5b). In the lowest depths, diffusion-driven natural convection occurs due to exchange of underground heat and interactions with the surrounding dirt. Above this lies the mixing zone, in which there is a combination of both natural convection (from underground sources) and forced convection (from the wind). Towards the top, forced convection from external wind and air sources tends to dominate [17].
Two primary thermal regulation mechanisms have been proposed, depending on whether the mound is closed (capped) or open (Appendix Fig. B1). For closed mounds, the thermosiphon flow model applies. The model shows that heat produced in the underground nests (on the order of 100 watts) provides enough buoyancy to drive the air up the mound towards the porous surface. At the surface, spent heat, gases, and water vapor is exchanged through the pores with the outside air. Since this refreshed, cooled air has higher density, it is then forced back down the mound to the underground nests, and the cycle repeats [17]. For open mounds, the induced flow model, also known as the stack effect, is invoked. The model assumes that the mound continuously interacts with the outside atmosphere through ground-level openings and tall chimney vents. Fresh air is drawn underground through the ground-level openings, where wind velocities tend to be lower, circulates through the nest, and finally is vented out the chimneys, where wind velocities tend to be higher. Unlike thermosiphon flow, induced flow is unidirectional, with heat flowing up and out [17]. As a result of this heat exchange, the termites are able to maintain their nests at nearly constant temperature and humidity despite outside temperatures varying between 3–42°C [19].
**Thermosiphon Heat Flow**

In mimicking the structure of termite mounds, the Eastgate Center draws on both the thermosiphon and induced heat flow models. Thermosiphon flow applies to heat that is generated and circulated internally by the building’s core materials, occupants, and office or retail spaces. Heat accumulates throughout the day with increased building use and activity, and subsides at nighttime when the building is unoccupied. Awareness of this thermal pattern is well-reflected in the building’s material selection. The building’s foundation is comprised of thick concrete slabs that have very high heat capacities. These slabs serve as heat sinks during the day, absorbing heat to prevent the temperature of the floor levels from rising too high. During the cooler night hours, the slabs slowly release the heat, which moves upward towards the chimney stacks. In this way, the concrete functions similarly to the natural convection zone of the termite mounds [16]. Thermosiphon heat flow is supplemented through the use of a fan-driven ventilation cycle. During the day, the fans operate on low volume, facilitating heat absorption into the building’s inner materials. During the night, they operate on higher volume, aiding heat flow out of the materials, towards the top of the building. This allows the materials to cool down so that they can effectively absorb heat again the following day [17].

**Induced Heat Flow**

As a complement to thermosiphon flow, induced heat flow is enabled through the building’s system of chimney stacks, which closely mimic the termite mounds’ chimneys [16]. Chimneys occur on two levels, through localized air vents on each floor and through tall, centralized ducts that run the length of the buildings. The localized air vents, like the ground-level openings of the termite mounds, facilitate circulation by expelling stale air into exhaust
ports located on each floor. Fans collect and transport this stale air to the tall, centralized ducts, which ultimately release the air to the outside atmosphere. The building also contains smaller openings like wind holes and air slits that further assist with localized circulation [17].

In addition to possessing this system of chimneys, the overall structure of the Eastgate Center closely resembles the structure of the termite mounds. The Center consists of two main buildings separated by a large central atrium. This open atrium resembles the porous openings of the termite mounds in their function, continuously facilitating air circulation with the outside atmosphere to maintain a cool internal temperature. Furthermore, the atrium is covered by a ventilated glass canopy. The canopy serves as a source of insulation, keeping the cool air of the atrium contained and balancing out the effects of heat released through the chimneys [21].

As a result, the Eastgate Center is able to maintain consistent internal temperatures in light of fluctuating external temperatures without relying on a costly air-conditioning system. By not investing in air-conditioning, the building was able to save 10% ($3.5 million) up-front in construction costs. Furthermore, rent of office space in the Eastgate Center is cheaper than in comparable buildings due to the reduced energy consumption [22].

![Fig. 6. Heat exchange in Eastgate Center. Both thermosiphon and induced flow are leveraged.](image-url)
4. Conclusion

The Gherkin Tower and the Eastgate Center serve as compelling examples of biomimetic architecture that have drawn inspiration from natural organisms to realize sustainable design. The steel and glass diagrid lattice of the Gherkin Tower resembles the multi-hierarchical silica exoskeleton of the Venus sea sponge, with both structures exhibiting exceptional rigidity and flexibility. Additionally, the spiraling, cylindrical form of the Gherkin Tower and its double skin façade windows enable natural ventilation that mimics the filtration mechanism of the sea sponge. As for the Eastgate Center, modeled after the mounds of *M. michaelseni* termites, heat exchange is facilitated through a combination of material selection and structural design. Thermosiphon heat flow arising from internal activity is moderated by high-thermal capacity concrete, while induced heat flow is facilitated by chimney stacks and a central open atrium.

While both buildings have mimicked nature to great effect, it is important to recognize that their success is a result of modeling both the form and the function of nature. As critics point out, biomimetic architecture can fall short of its potential when buildings merely copy the shape of natural organisms, without understanding and interpreting how those forms could be leveraged to yield tangible improvements in performance. This complication is both exacerbated and enhanced by the highly interdisciplinary nature of biomimetic architecture. Lying at the intersection of art and science, the field is uniquely positioned to balance aesthetic and technical considerations in search of increasingly stable and efficient solutions [24]. By striving past superficial mimicry towards fundamental, underlying insights, sustainable design can be realized – one that both impacts and lasts.
5. References


6. Appendix

Appendix A: The Gherkin Tower and the Venus Sea Sponge

Fig. A1. Diagrid lattice structure. The diagrid arrangement of the frames and the structure of the nodes provide resistance against vertical, overturning, and horizontal loading.
Fig. A2. **Aerodynamic form.** The curved, aerodynamic form of the building directs wind to flow smoothly around it, preventing it from bouncing off to hit ground-level pedestrians.

**Appendix B: The Eastgate Center and Termite Mounds**

Fig. B1. **Thermosiphon and induced flow models.** The thermosiphon model applies to thermal regulation in closed (capped) mounds, while the induced flow model applies to open mounds.