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Nature-Inspired Buildings: How Plants and Animals Help Us Design Better Cities

BIOS4YOU AR 2.0

BIO-INSPIRED STEM TOPICS FOR ENGAGING YOUNG GENERATIONS THANKS TO THE USE OF AUGMENTED REALITY

Project Number: KA220-BW-23-30-126516

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General topic of the learning path	Nature-Inspired Buildings: How Plants and Animals Help Us Design Better Cities
Specific name of the learning unit	Bio-Design in Urban Architecture
Target user age	14-18 years
Learner prerequisites	Biology, Physics, and Environmental Science
Description of the learning unit	This learning unit guides students and teachers in exploring how the natural strategies of plants and animals can inspire sustainable solutions in architecture and urban planning. Through a multidisciplinary approach and the use of Augmented Reality (AR) tools, learners will discover how biological systems can lead to innovative building and city design that responds to climate, function, and well-being
Subject involved	Biology, Physics, Environmental Science, Art/Design, Geography, Mathematics
Keywords	Biomimicry, Nature-Inspired Architecture, Sustainable Cities, Bio-design, Urban Ecology, Green Innovation, AR, Interactive Learning
Key-skills, abilities, knowledge that can be acquired	Understand how biological principles can be applied to architectural and urban challenges Identify examples of bio-inspired buildings and the natural organisms that inspired them Learn how to design climate-responsive structures using nature as a model Develop creativity and problem-solving through AR-based design activities Explore the concept of regenerative and sustainable urban environments
Resources and didactic tools used	Research papers, books, scientific databases, webinar results, web-based resources, AR tools (e.g., JigSpace, Assemblr EDU, Merge Cube, CoSpaces Edu).
Evaluation criteria and assessment	Based on the knowledge, abilities, and skills gained during the course, including AR-based assessments such as simulations, prototyping, and feedback.

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Introduction

Cities have become central to human life and development as the world urbanizes. With global population growth accelerating, urban areas absorb most of this increase. According to the UN-Habitat report (Judith Oginga, 2022), it is estimated that by 2050, nearly 70% of the world's population will live in cities. This rapid urban expansion places immense pressure on natural systems, as cities depend heavily on external resources to sustain their operations and inhabitants.

Historically, many urban environments have been designed without consideration for their surrounding ecosystems. As Othmani et al. (2022) noted, many built environments have developed as though separate from nature, resulting in structures and systems that often disrupt ecological balance. This disconnect has led to fragile urban systems that are ill-equipped to respond to climate change, biodiversity loss, and resource depletion. To create more resilient cities, future development must align with ecological principles, supporting human wellbeing, regenerative resource use, and integration with the natural environment.

In response to the environmental degradation caused by urbanization, cities worldwide are beginning to implement solutions that seek a better balance between society and nature. One emerging approach is the use of nature-based solutions (NbS). The World Bank first introduced this concept in 2008, and it was formally defined by the European Commission in 2015 (Sowińska-Świerkosz and García, 2022). The European Commission describes NbS as actions inspired by, supported by, or directly modeled on nature. Similarly, the International Union for Conservation of Nature (IUCN) defines nature-based solutions as "actions to protect, sustainably manage and restore natural or modified ecosystems" (Matthews et al., 2022).

Recent studies highlight that the role of NbS in cities goes beyond ecological restoration. While these strategies are vital for improving biodiversity, they also offer broader benefits at the social and economic levels. For example, integrating green infrastructure such as urban forests, wetlands, or green roofs can improve public health, enhance climate resilience, create local jobs, and contribute to social cohesion. As such, nature-based solutions are increasingly recognized as essential tools for building sustainable, inclusive, and resilient urban environments.

In the face of rapid urbanization, environmental degradation, and the escalating impacts of climate change, rethinking the design of our cities has become a global imperative. Conventional urban development methods rely on resource-intensive technologies contributing to pollution, energy waste, and ecosystem disruption. A promising alternative gaining traction across architecture and urban planning is the concept of bio-inspiration, also known as biomimicry. This approach involves studying and emulating the strategies found in nature to solve human design challenges. Through 3.8 billion years of evolution, nature has developed highly efficient and resilient systems that sustain life without exhausting resources. As Benyus (1997) famously stated, "Life creates conditions conducive to life", a philosophy at the heart of biomimetic thinking.

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A compelling example of bio-inspiration in practice is the Eastgate Centre in Harare, Zimbabwe. This building, designed by architect Mick Pearce, draws directly from the structure of termite mounds, which can maintain internal temperature stability through passive ventilation mechanisms. As Kennedy et al. (2015) described, the Eastgate Centre uses this model to reduce energy consumption by up to 90% compared to traditional buildings with mechanical climate control systems. This case illustrates how understanding biological principles can lead to transformative improvements in energy efficiency and sustainability.

Another widely studied case involves the lotus leaf, whose microscopic surface structure causes water to bead and roll off, cleaning the leaf. This has inspired the development of self-cleaning materials now used in architecture, reducing water usage and maintenance costs (Vincent et al., 2006). Likewise, cactus skin's heat-reflective and water-collecting features have influenced building designs in arid regions that require innovative thermal and water management solutions.

Beyond individual building elements, biomimicry also offers systems-level insights. The branching patterns of trees and root networks have been applied to optimize the layout of urban transportation and water systems, modeling efficient distribution networks and minimizing energy loss across a city (Vincent et al., 2006). These examples highlight how bio-inspiration is a creative, scientific, and strategic process rooted in observation, analysis, and systems thinking.

To make these concepts accessible and engaging to high school students (ages 14–18), this training unit incorporates Augmented Reality (AR) as a central tool. AR allows learners to explore natural systems in 3D, interact with hidden biological structures, and compare them directly to human designs. This immersive experience supports conceptual learning and creative exploration, providing a bridge between biological science, environmental education, and digital technology. By designing their nature-inspired buildings in AR, students can experiment with ideas without material constraints, fostering sustainability awareness and innovative thinking.

Ultimately, this unit aims to inspire the next generation of architects, engineers, and environmental stewards by showing them that some of the most innovative solutions for urban design have already been invented by nature. Through hands-on interaction and scientific reflection, students will see the built environment not as separate from the natural world, but as something that can learn from and coexist with it.

Nature as a model in the built environment design

Nature has long served as an inspiration for architecture, influencing various design movements throughout history. From Gaudí's biomorphic forms to the structural elegance of Santiago Calatrava's contemporary works, both draw heavily from patterns and geometries in the natural world. While earlier nature-inspired architecture often focused on aesthetics, there is now a growing trend toward interdisciplinary design that seeks more than visual inspiration. This emerging approach incorporates biological strategies that help reduce natural resource consumption and lower carbon emissions, aligning architecture with the transition from an industrial to an ecological era (Dixit and Stefańska, 2023).

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The ability of nature to adapt to changing environmental conditions has been well-documented across scientific disciplines (Jamei and Vrcelj, 2021). As Wu et al. (2020) noted, a key goal of bio-inspired design is to restore environmental functions and landscape patterns, transforming the built environment into a more efficient, low-carbon, and resilient system. China provides a noteworthy example, where implementing sustainable ecological principles over the past 50 years has led to the development of towns designed to regenerate natural ecosystems. These "eco-cities" emphasize integrated solutions across five fundamental systems: energy, food, transport, waste, and water.

In the built environment, bio-inspired design has manifested in various ways, especially through the growing adoption of biomimicry. Over the past decade, biomimicry has become a defining aspect of many modern architectural projects. According to Ferwati et al. (2019), nine key characteristics have emerged in biomimetic design practices: form and function, geometry, metaphor, material, movement, pattern, proportion, sustainability, and technology. These characteristics reflect the diverse ways in which natural principles are translated into architectural language.

Recent scholarship also emphasizes the conceptual framing of nature as a guide in the design process. Oguntona and Aigbavboa (2023b) argue that viewing nature as a mentor makes the natural ecosystem a valuable reference point for continuous learning and creative innovation. They identify three core dimensions in bio-inspired design: imitation, emulation, and inspiration. These dimensions allow designers to explore nature for structural models and process-driven and systems-based strategies. As Oguntona and Aigbavboa (2023a) further note, integrating these approaches into the design of the built environment holds excellent potential for reducing environmental degradation and minimizing resource exploitation.

Nature’s Solutions to Human Challenges

In the face of escalating environmental and social challenges, cities worldwide are under increasing pressure to become more sustainable, resilient, and adaptive. Traditional approaches to urban planning often fail to address these complex demands, prompting many architects, engineers, and designers to seek guidance from the natural world. This approach, known as bio-inspiration or biomimicry, involves studying the forms, processes, and systems developed by nature over billions of years and translating their underlying principles into human-centered design solutions. Unlike simple imitation, biomimetics, as defined by Vincent et al. (2006), focuses on extracting functional strategies from biological systems to solve human problems in innovative and sustainable ways. Nature offers a vast repository of tested solutions, each refined through evolutionary trial and error to achieve maximum efficiency with minimal waste. In this section, we explore how bio-inspired thinking can be applied to five critical urban challenges, revealing how organisms and ecosystems can help us reimagine the future of our cities.

- Passive Temperature Regulation

Managing indoor temperature without heavy reliance on energy-intensive systems is one of the foremost challenges in urban architecture. For instance, termite mounds in sub-Saharan Africa

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maintain a stable internal temperature despite external fluctuations by utilizing complex tunnel systems that facilitate passive airflow. This natural mechanism inspired the design of the Eastgate Centre in Harare, Zimbabwe, a commercial building that uses similar passive ventilation techniques to reduce energy consumption by up to 90% compared to traditional buildings (Turner & Soar, 2008).

- Water Collection and Conservation

Plants and animals have evolved highly specialized methods to harvest and conserve water in arid environments. The cactus employs a ribbed surface to direct dew efficiently toward its roots. At the same time, the Namib Desert beetle uses alternating hydrophobic and hydrophilic patterns on its shell to condense and collect water from the air. Inspired by these organisms, engineers have developed fog-harvesting buildings and roofing systems capable of extracting water from the atmosphere without relying on pumps or chemicals (Nørgaard et al., 2012).

- Self-Cleaning and Low-Maintenance Surfaces

Building maintenance often requires significant use of water and chemicals. However, in nature, the lotus leaf has evolved a nano-structured surface that repels water and carries away dirt particles as it dries. This phenomenon, known as the lotus effect, has led to the development of self-cleaning glass, solar panels, and façade coatings that reduce maintenance needs while increasing durability and cleanliness (Barthlott & Neinhuis, 1997; Koch et al., 2009).

- Lightweight but Resilient Structures

Nature often achieves remarkable strength using minimal material. Spider silk is a standout example, offering a tensile strength greater than steel relative to its weight. Honeycomb structures in beehives and other organisms distribute stress efficiently while conserving material. These models are widely used in modular construction, aerospace, and architectural panel design to reduce load and resource use while maintaining structural integrity (Fratzl & Barth, 2009; Vincent et al., 2006).

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Efficient Urban Planning and Flow

In natural systems, the branching structures of trees, root networks, and vascular systems are optimized to distribute resources such as water, nutrients, and energy with minimal resistance. Urban planners and infrastructure designers have increasingly turned to these natural patterns to inform the design of transportation networks, pedestrian pathways, and utility systems. These biomimetic designs enhance connectivity, reduce congestion, and allow decentralized energy and water distribution, improving resilience and efficiency. As Badarnah (2017) emphasizes, biomimetic principles derived from ecological branching systems offer practical strategies for adapting cities to complex environmental and social demands while maintaining harmony with the natural landscape.

Biomimicry can be applied at three levels: form, process, and system-level. The form level involves emulating the function derived from the specific form of an organism, a part of it, or its production. This level focuses on the morphology found in nature. The process level of biomimicry mimics the behavior or production processes of organisms or groups of organisms. Lastly, the system-level biomimicry emulates ecosystems' functioning, principles, and strategies (Jain et al., 2023). In the context of cities, complex systems comprising humans, infrastructures, environmental context, and relationships, ecosystems serve as the most relevant and fitting level of inspiration. Ecosystems consist of biotic elements, analogous to the built components of a human city, and abiotic elements, which can be compared to the urban environment and context. Additionally, ecosystems encompass interactions among these elements.

Madmar et al. (2023) proposed a parallel between an ecosystem’s composition and an urban system’s composition and functioning in Figure 1. While ecosystem-level biomimicry can incorporate form and process-level biomimicry, it systematically considers the larger-scale benefits. This approach provides more comprehensive and attuned solutions to cities' systematic challenges. Past analogies between the human organism and current works on urban metabolism are limited and primarily address the issue of urban flow (Dicks et al., 2021).

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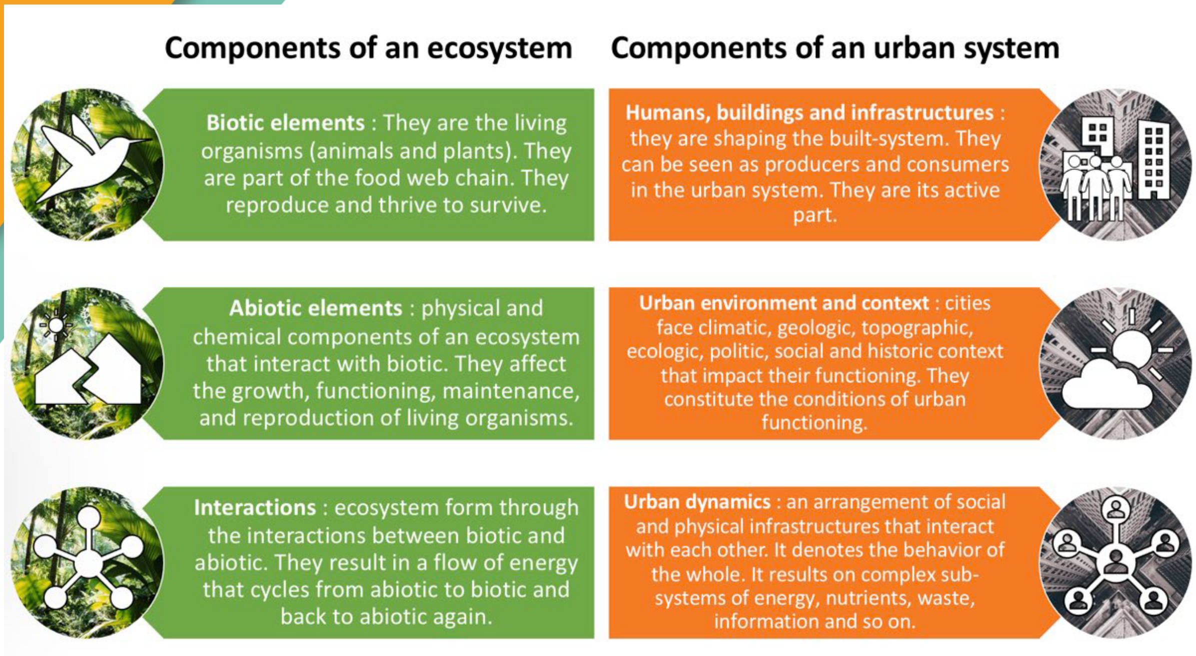

Fig 1. Parallel between ecosystem and urban system composition and functioning, Source: Dicks et al., 2021

Bio-Inspired approaches:

Approaches inspired by nature have been present in many fields, including architecture and urban planning, with bionics, biomimetics, and biomimicry being the three bio-inspired design approaches commonly referred to. As a general terminology, Bionics began to be implemented in 1958 by Jack Steel as a combination of biology and technique; it focuses on the mechanical abilities of nature, extracting its physical principles as inspiration for developing a technical design. However, its practice can lead to unsustainable solutions since it does not consider the interaction of these solutions with sustainability (Landrum and Mead, 2022). Meanwhile, through understanding and analysis, biomimetics transfers characteristics, qualities, and systems from nature to the artificial environment (Urdinola-Serna and diseño, 2018). The term biomimetic, which comes from the roots bios (life) and mimesis (imitate), dates to 1969, thanks to the biophysicist and engineer Otto Schmitt, and focuses mainly on imitating nature, both in application and form. Finally, biomimicry was defined by Benyus in 1997 as the science that imitates the models of nature. That, in turn, uses an ecological standard that measures its interaction with the environment, which takes it one step beyond bionic and biomimetic, worrying about sustainability in its application (Landrum and Mead, 2022).

The biomimicry design process typically follows a bidirectional methodology that includes two complementary approaches, as outlined by Bader et al. (2021), Chayaamor-Heil (2023), and Urdinola-Serna and Diseño (2018). The first is the problem-oriented approach, where designers begin by identifying a specific design challenge or objective. Once the problem's parameters are clearly defined, they look to nature for strategies used by plants, animals, or ecosystems that might provide viable solutions.

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The second is the solution-oriented approach, often from the biological sciences. In this method, researchers or scientifically informed designers begin by studying biological systems or behaviors that exhibit interesting or effective functions. These natural strategies are then analyzed for their potential relevance to human design problems, allowing biological insights to guide the development of innovative architectural or engineering solutions.

Together, these two approaches reflect the interdisciplinary nature of biomimicry, allowing design problems and biological knowledge to inform one another in a continuous, iterative process.

How biological systems inspire sustainable design

Bio-inspired design, or biomimicry, is increasingly recognized as a creative approach and a rigorous scientific methodology for addressing sustainability challenges in the built environment. According to Aamer et al. (2020), biomimicry allows designers to move beyond superficial imitation of nature and toward a deeper integration of biological principles into building performance. This involves analyzing how organisms adapt to their environment, manage energy, water, and material flows, and how their internal behaviours can inspire systemic architectural solutions.

A key concept is the closed-loop material and energy flow observed in ecosystems. In a forest, waste from one organism becomes food for another; nothing is discarded. Urban designers are beginning to adopt this model through circular urban systems, where waste, water, and energy are recycled. This systems-level thinking reflects the logic of ecosystems and supports more resilient urban infrastructure (Kennedy et al., 2015). Even the structure of organisms influences design. For instance, the form of the boxfish has inspired aerodynamic cars and building facades due to its optimized structure for reducing drag (Bar-Cohen, 2012). These examples illustrate that nature provides both functional models and design principles that can directly inform how we shape future cities.

One of the most critical shifts advocated in recent research is from mimicking the form of nature to understanding and replicating its function and behaviour. Aamer et al. (2020) emphasize the importance of this transition by highlighting the gap in past architectural practices, which often used natural aesthetics without achieving functional sustainability. Through a problem-based biomimetic approach, they propose a methodology that focuses on building behaviour, including energy efficiency, thermal comfort, material performance, and environmental responsiveness. This process starts with identifying architectural challenges and seeking solutions from biological role models that have evolved to overcome similar conditions.

The methodology described in their study includes simulating biological systems through experimental abstraction and translating these into architectural prototypes. It spans three levels of biomimicry: organism level (specific form or function), behaviour level (interaction with environment), and ecosystem level (systemic flows and relationships). The behaviour level is particularly emphasized, as it enables buildings to respond adaptively, similar to how living organisms regulate heat, moisture, or light.

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- Levels in biomimicry design

Biomimetic design can be applied at different levels depending on how designers interpret and extract natural ideas. According to Bader et al. (2021) and Chayaamor-Heil (2023), biomimicry operates on three primary levels: organism, behavior, and ecosystem.

The organism level involves direct inspiration from a specific plant or animal. This might include replicating the entire organism or focusing on a particular structural or functional characteristic that can be applied to a design challenge. The behavior level focuses on how a living organism interacts with its environment. This includes studying adaptive actions, such as how particular species manage temperature, moisture, or movement to their surroundings. The ecosystem level takes a broader approach, drawing from the principles that allow ecosystems to function efficiently and sustainably. These include energy cycling, biodiversity, symbiotic relationships, and resilience.

Further refinement of biomimetic interpretation is found in the work of Mirniazmandan and Rahimianzarif (2017), who propose five sub-levels of imitation: form, material, construction, process, and function. These allow designers to isolate specific aspects of biological systems that may be relevant to the built environment. In addition, Oguntona and Aigbavboa (2023a) describe three conceptual approaches to working with bio-inspiration: imitation, emulation, and inspiration. These dimensions range from directly copying nature’s forms to drawing abstract ideas and applying them creatively to solve design problems.

A related concept that supports the shift toward nature-integrated design is biophilia. While not technically classified under bio-inspired design, biophilic design promotes the connection between humans and the natural world. Defined by Edward O. Wilson and Stephen Kellert, biophilia refers to the inherent human tendency to seek contact with nature. This concept is rooted in our evolutionary history and biological development. According to Calabrese (2015), biophilic design aims to restore this lost connection in modern environments by incorporating environmental features, natural forms, daylight, spatial variety, and local identity. These strategies contribute to spaces that support human wellbeing in cognitive, emotional, and physical dimensions.

In addition to biomimicry and biophilia, there is a growing interest in distinguishing between nature-based solutions (NbS) and nature-inspired solutions (NiS). Nature-based solutions are typically linked to living ecosystems and rely on their continued ecological functions to deliver water purification, carbon storage, or climate regulation benefits. In contrast, nature-inspired solutions, including biomimicry, are derived from principles and strategies observed in nature but do not require functioning ecosystems to work. As IUCN (2020b) outlined, NiS refers to innovative systems, materials, or processes designed using insights from biology, enabling scalable applications in architecture and engineering.

Applying biomimetic design allows us to view nature not just as a source of beauty or inspiration but as a source of knowledge and innovation. By translating natural strategies into architectural

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systems, designers can create buildings and infrastructures that are regenerative, adaptive, and resilient. The following table presents selected examples of biological systems and their corresponding architectural applications, demonstrating how biomimicry continues to shape the future of sustainable design.

Table 1- Biological Systems and Their Architectural

Biological Model	Natural Strategy	Architectural/Urban Application	Challenge Addressed	Source
Termite mound	Passive airflow regulates internal temperature	Eastgate Centre (Zimbabwe)	Energy-efficient climate control	Turner & Soar, 2008
Lotus leaf	Micro/nano-texture causes water and dirt to roll off	Self-cleaning windows, façades, and solar panels	Maintenance reduction, water savings	Barthlott & Neinhuis, 1997; Koch et al., 2009
Cactus skin	Ribbed and waxy surface directs dew and limits evaporation	Water-collecting walls and desert architecture	Water harvesting and conservation	Ju et al., 2012
Namib Desert beetle	Hydrophilic and hydrophobic patterns capture moisture	Fog-harvesting surfaces and roofs	Access to atmospheric water	Nørgaard et al., 2012
Spider silk	High tensile strength and flexibility	Lightweight tension structures, composites	Material efficiency and resilience	Fratzl & Barth, 2009
Honeycomb structure	Geometric efficiency with minimal material	Lightweight panels, modular construction	Strength with less material	Vincent et al., 2006

To fully understand the potential of bio-inspiration in sustainable architecture, it is essential to move from theoretical principles to real-world applications. Biological organisms offer diverse strategies developed through millions of years of adaptation, methods that can directly inform how we design, build, and operate urban environments. In the context of biomimicry, success lies not in copying nature's appearance but in translating its functions, behaviours, and systems into human design in meaningful and measurable ways.

The following sections highlight three well-researched biological models, termite mounds, lotus leaves, and tree/root branching systems, that have inspired innovative architectural and urban solutions. These examples illustrate how biological strategies have been adapted into building systems to solve challenges such as climate control, water conservation, self-maintenance, and resource distribution. Each case connects directly to a practical application and is supported by scientific research.

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Together with the following table, these case studies provide a foundation for understanding the depth and versatility of bio-inspired design. They showcase how learning from nature's "design textbook" can produce more innovative, resilient, and sustainable human environments.

Termite Mounds: Passive Thermal Regulation and Ventilation

Termite mounds, especially those constructed by *Macrotermes* species in sub-Saharan Africa, are sophisticated natural structures that maintain a remarkably stable internal temperature and humidity, despite extreme external climate conditions. This is achieved through an intricate network of air shafts and tunnels that promote passive ventilation. The termites use a system of controlled openings and chambers to drive convective airflow, regulating the mound's internal microclimate to support their symbiotic fungus farming.

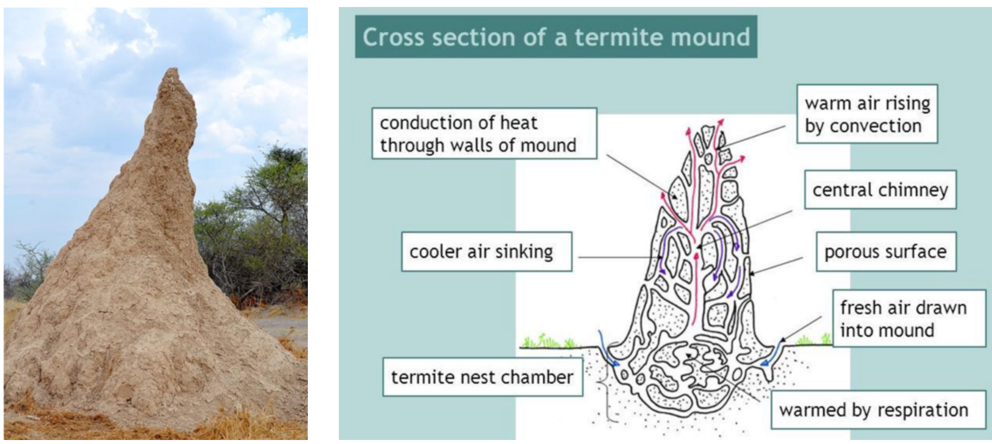

Fig 2. Termite Mounds and it's ability, source:
https://www.mickpearce.com/assets/images/biomimicry-architecure-09-1400x2133-77.jpg

This natural model has inspired architects and engineers to develop energy-efficient buildings that regulate indoor temperature without relying heavily on mechanical systems. The most famous application is the Eastgate Centre in Harare, Zimbabwe, designed by architect Mick Pearce in collaboration with engineer Arup Associates. The building mimics termite mound principles to passively regulate air flow and temperature passively, reducing its energy consumption for ventilation and cooling by over 90% compared to conventional buildings of similar size (Turner & Soar, 2008).

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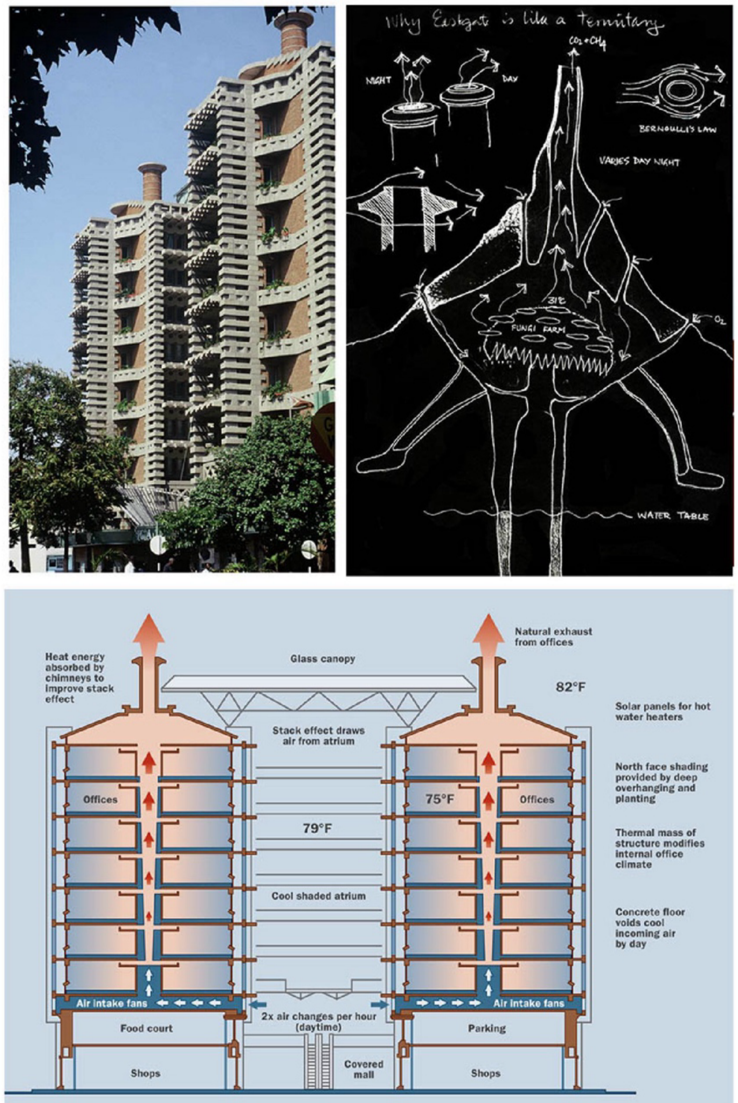

Fig 3. Eastgate Centre in Harare, Zimbabwe, source: https://www.mickpearce.com/assets/images/biomimicry-architecure-09-1400x2133-77.jpg

Lotus Leaf: Self-Cleaning Surfaces

The lotus plant (*Nelumbo nucifera*) thrives in muddy aquatic environments, yet its leaves remain impeccably clean. This is due to the micro- and nanostructures on the leaf surface, which create a superhydrophobic effect, water droplets bead and roll off the surface, collecting and carrying away dirt particles. This phenomenon is commonly known as the "lotus effect".

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Fig 4. Lotus leaf effect, source: https://www.properla.co.uk/lotus-effect/

Inspired by this self-cleaning mechanism, materials scientists and architects have developed hydrophobic coatings for windows, solar panels, building facades, and tiles that repel water, thereby reducing maintenance costs. These materials reduce water consumption for cleaning and extend the lifespan of surfaces exposed to the elements. The innovation supports sustainable architecture by minimizing resource use and labor while maintaining visual and functional integrity.

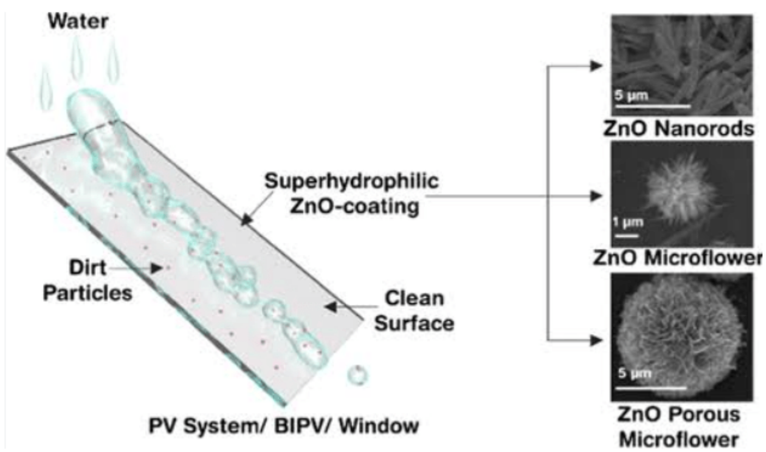

Fig 5. Hydrophilic and Superhydrophilic self-cleaning coatings by morphologically varying ZnO microstructures, source: https://shop.nanografi.com/blog/following-the-natures-lead-lotus-effect-

Namib Desert Beetle: Water Harvesting from Air

The Namib Desert beetle (Stenocara gracilipes) thrives in one of the driest places on Earth by harvesting water from fog. Its elytra (hardened wing covers) are textured with hydrophilic bumps surrounded by hydrophobic valleys, allowing it to capture and direct atmospheric moisture toward its mouth. As Nørgaard et al. (2012) explain, the beetle uses a distinct fog-basking behavior, orienting its body into the breeze during early morning fogs to maximize water collection. This passive system enables the beetle to survive without any active energy expenditure, making it an ideal model for sustainable water technologies.

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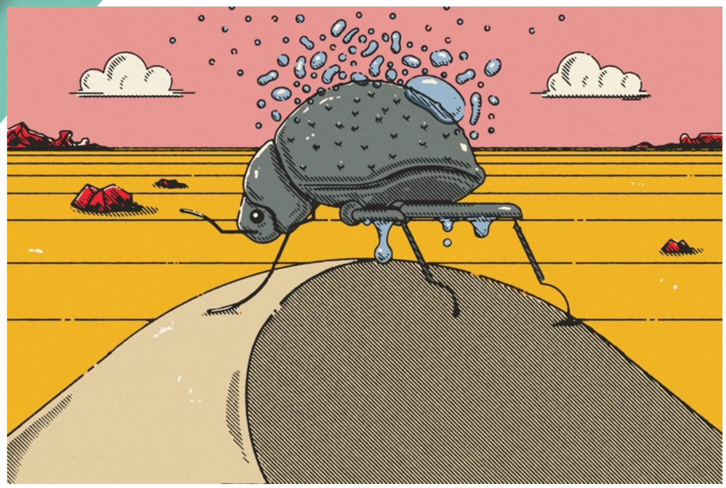

Fig 6. Namib Desert beetle and harvesting water, source:
https://www.atlasobscura.com/articles/fogstand-beetles-namib-

The beetle's microstructural surface and behavioral strategy have inspired the development of biomimetic materials and surfaces that mimic its water collection method. Engineers have created synthetic surfaces with patterned wettability to condense and funnel water from fog, dew, or humid air. These have been used in fog nets, façade panels, and rooftop systems, especially in water-scarce regions like Chile, Ethiopia, and the UAE. These systems offer a passive and sustainable solution to freshwater scarcity in remote or drought-prone areas by replicating the beetle's efficiency.

Architectural applications continue to evolve, integrating these materials into building envelopes that shelter and function as water-harvesting tools, reducing reliance on centralized infrastructure and promoting environmental resilience.

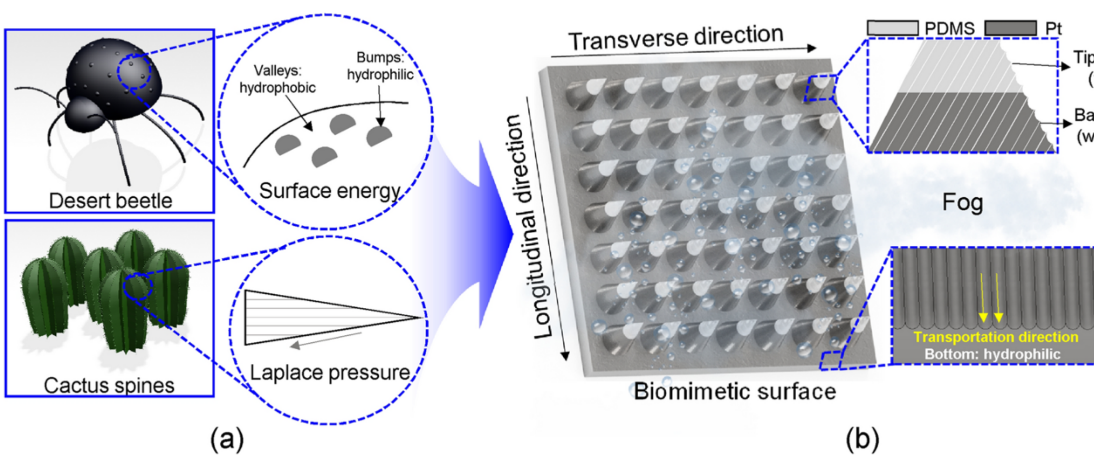

Fig 7. (**a**) Illustration of the characteristics of both elytra of the Namib Desert beetle and cactus spines; (**b**) schematic of the hierarchically structured biomimetic surfaces inspired by the elytra of the Namib Desert beetle and cactus spines. Source: https://www.nature.com/articles/s41598-023-37461-x/figures/1

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Execute:

Harnessing Augmented Reality to Explore Nature-Inspired Design in STEM Education

In the evolving STEM education landscape, integrating bio-inspiration and drawing design principles from nature offers a highly engaging pathway to connect students with real-world sustainability challenges. Augmented Reality (AR)emerges as a transformative tool in this context, bridging the gap between abstract biological concepts and tangible architectural applications for high school students aged 14 to 18.

Recent research emphasizes that AR technologies significantly enhance student engagement and deepen understanding. Through AR, students can interact with three-dimensional models of biological structures, such as the microstructure of lotus leaves or the ventilation system of termite mounds, projected into their physical environment. This immersive experience helps learners to visualize, manipulate, and better comprehend complex STEM concepts (BestColleges, 2024).

Moreover, AR supports visualizing intricate natural systems that might be difficult to capture through traditional teaching methods. In bio-inspired design education, AR enables students to dynamically explore how natural adaptations, like the water-collection mechanisms of desert beetles or the self-shading properties of cactus skins, can inspire architectural innovation. Studies have shown that AR in STEM contexts can foster critical thinking, creativity, and spatial reasoning, crucial skills for future engineers and designers (Frontiers in Education, 2024).

In addition, AR technologies offer flexibility and inclusiveness by catering to different learning paces and styles. Students can engage individually or collaboratively, constructing knowledge to suit their learning preferences. Such flexibility contributes to greater accessibility and student satisfaction in STEM education environments.

Finally, integrating AR into bio-inspiration education allows students to engage with theoretical knowledge and authentic problem-solving experiences. Designing a biomimetic facade to reduce urban overheating or conceptualizing a shading system based on plant behavior provides students with interdisciplinary skills at the intersection of biology, technology, and architecture. This holistic approach nurtures innovation, sustainability thinking, and real-world readiness.

In summary, integrating AR tools into bio-inspiration-focused STEM education creates dynamic, inclusive, and future-oriented learning experiences that empower students to innovate by learning from nature.

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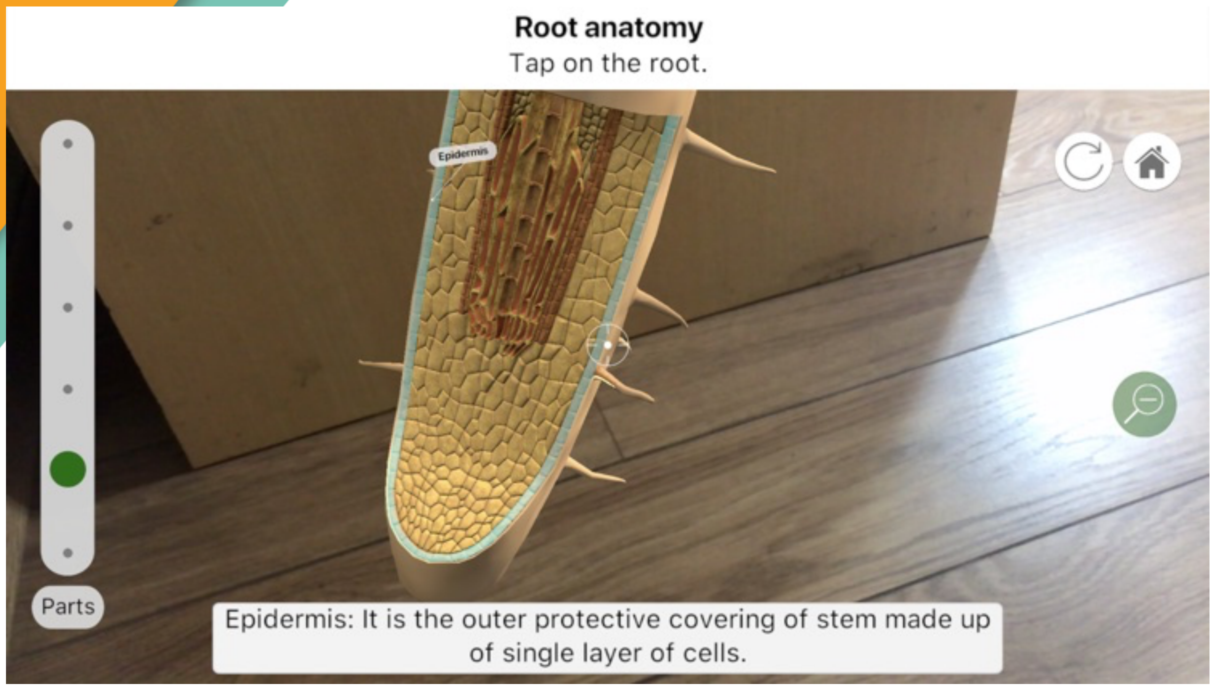

Plantale App

As augmented reality (AR) technology continues to gain momentum in education, various schools and educational initiatives have already demonstrated its potential to enhance STEM learning through bio-inspiration. These projects showcase how AR can immerse students aged 14 to 18 in observing biological phenomena, understanding natural principles, and creatively applying them to engineering and design challenges. The following examples illustrate how AR has been successfully integrated into bio-inspired STEM education environments to foster deeper engagement, conceptual understanding, and innovation skills.

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Phase	Description
Explore	- Research and Discovery: Investigate biological systems (e.g., termite mounds, lotus leaves, bird nests) and their relevance to architecture.
	- Content Development: Develop foundational materials explaining how biological functions can be applied to architectural elements (e.g., ventilation, insulation, structure).
	- Needs Analysis: Identify knowledge gaps and learning opportunities in bio-architecture and sustainable urban design.
Execute	- Curriculum Implementation: Deliver interdisciplinary lessons combining biology and architecture (e.g., how cactus skin informs water collection surfaces).
	- Interactive Exercises: Engage students with hands-on activities and AR simulations to model nature-inspired building features.
	- Feedback Collection: Gather insights from learners and educators to improve the integration of biological concepts into design thinking.
Enhance	- AR Integration: Apply AR to visualize and interact with biomimetic building elements (e.g., simulate airflow in termite-inspired ventilation systems).
	- Interactive Learning: Students manipulate 3D biological models and architectural analogs, bridging nature and the built environment.
	Gamified Content: - Points and Badges: Earn rewards by identifying biological strategies and linking them to architectural solutions (e.g., mimic lotus effect for facade self-cleaning). - Leaderboards: Foster friendly competition on tasks like matching natural systems with their built counterparts. - Quests and Levels: Advance through biomimicry challenges, from basic biological concepts to complex design applications. - Rewards for Exploration: Discover hidden architectural strategies within AR models of animal habitats or plant structures. - Collaborative Gamified Tasks: Work in teams to design nature-inspired city zones, using AR to simulate environmental impact and energy efficiency.
	AR-Based Assessments: - Use AR to assess understanding by having students demonstrate the translation of a biological principle (e.g., the structure of honeycombs) into a building component (e.g., modular wall systems).

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BIO-INSPIRED STEM TOPICS FOR ENGAGING YOUNG GENERATIONS
THANKS TO THE USE OF AUGMENTED REALITY

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