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Next-Generation Eco-Materials: Innovations Shaping Sustainable Architecture

BIOS4YOU
AR 2.0
BIO-INSPIRED STEM TOPICS FOR ENGAGING YOUNG GENERATIONS THANKS TO THE USE OF AUGMENTED REALITY

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Table of Contents

Project Number: 2023-1-DE03-KA220-SCH-000126516

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Image 1. Next-Generation Eco-Materials: Innovations Shaping Sustainable Architecture

General topic of the learning path	Eco-Friendly Materials in Construction
Specific name of the learning unit	Next-Generation Eco-Materials: Innovations Shaping Sustainable Architecture
Age of the target users	14-18 years
Requirements for the learner	1. Basic understanding of environmental science concepts (e.g.,eco-material,). Basic literacy and numeracy skills. Basic ICT skills. 2. Access to a computer or tablet with internet connectivity. 3. Willingness to engage with digital tools (AR apps, Delightex). 4. No prior coding or AR development experience required, as CoBlocks is beginner-friendly.
Description of the learning unit	This unit introduces students to the concept of eco-friendly materials in construction, focusing on cutting-edge innovations transforming sustainable architecture. It is divided into three sections: "Explore" introduces foundational concepts of eco-materials and sustainable construction. "Execute" delves into bio-inspiration, showcasing how natural processes inspire solutions and how Augmented Reality (AR) can visualize these processes and impacts, supported by real-world examples and practical activities. "Enhance" justifies the pedagogical benefits of AR, offering examples of useful AR applications and practical integration strategies. The unit culminates in a hands-on exercise where students use a gamified AR experience in Delightex to

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	strengthen their understanding and engagement with the topic.
Subject: Parties involved	Environmental Science, Biology, Geography, Digital Literacy/Computer Science, Art & Design, Social Studies, Mathematics, Language Arts (research, communication)
Keywords	Eco-materials, Nature-Based Solutions, Bio-inspiration, Biomimicry, Environmental Education, Sustainability, Sustainable Construction, Digital Literacy, Augmented Reality (AR), Gamification.
Key qualifications, skills and knowledge that can be acquired	Qualifications (Mindset/Attitude): ● Environmental awareness. ● Proactive and innovative thinking towards environmental challenges. ● Appreciation for nature's role in sustainable solutions. ● Motivation to participate in climate action. Skills: ● **Critical Thinking:** Analyzing environmental problems and proposing solutions. ● **Problem-Solving:** Applying bio-inspired concepts to environmental challenges. ● **Communication:** Explaining complex environmental concepts and presenting ideas. ● **Digital Literacy:** Navigating and utilizing AR applications. ● **Scientific Inquiry:** Interpreting data and observing natural processes (virtual or real). Knowledge: ● Understanding different types of eco-materials and their unique characteristics. ● Understanding the causes and impacts of traditional vs. bio-based materials (e.g., carbon footprint, embodied energy) ● Recognising bio-inspired solutions derived from nature.

Project Number: 2023-1-DE03-KA220-SCH-000126516

	● Understanding the potential and applications of Augmented Reality in environmental education.
Resources and didactic aids used	Resources: ● Textbooks/Scientific articles ● Case studies ● Internet resources ● Free AR platforms (Delightex) ● AR-compatible devices (smartphones/tablets)
Assessment criteria and evaluation	● **Participation:** Engagement in discussions and activities throughout the unit. ● **Activity Completion:** Execution of practical AR exercise ● **Concept Map/Mind Map:** Creation of a visual representation linking climate change, ecosystems, restoration methods, and bio-inspired solutions.

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Introduction:

The construction sector is essential to creating a sustainable future as environmental issues on our planet worsen. The cutting-edge materials and technologies that are transforming building construction will be covered in this unit, with an emphasis on environmentally friendly substitutes that lessen their negative effects on the environment and encourage healthier living environments. We will explore the fascinating field of sustainable architecture, learn how innovative solutions are inspired by nature, and examine how Augmented Reality (AR) can revolutionize our understanding of these important subjects. You will have a solid understanding of eco-materials and how they can help create a more sustainable built environment by the end of this unit.

1. Explore – Foundations of Next-Generation Eco-Materials

The construction industry is a significant contributor to global resource depletion, energy consumption, and waste generation. Traditional building materials often have a high carbon footprint due to their extraction, manufacturing, transportation, and disposal. Next-generation eco-materials aim to address these challenges by offering sustainable alternatives that minimize environmental harm throughout their lifecycle.

1.1 What are Next-Generation Eco-Materials?

Next-Generation Eco-Materials, often referred to as sustainable, green, or environmentally friendly materials, are construction products and technologies designed to minimize negative environmental impacts throughout their entire life cycle, from extraction and manufacturing to use, disposal, and potential reuse or recycling. Unlike traditional materials that can be resource-intensive, energy-consuming, and waste-generating, eco-materials prioritize resource efficiency, reduced pollution, and long-term sustainability. They aim to support ecological balance while meeting functional and aesthetic building requirements.

To fully perceive the importance of eco-materials, it's essential to understand several interconnected concepts:

- **Life Cycle Assessment (LCA):** The process of evaluating the environmental effects of a product at every stage of its life cycle, from the extraction of raw materials through material processing, production, delivery, use, service and repair, and disposal or recycling, is known as life cycle assessment, or LCA. A

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low environmental impact at each of these stages is a crucial feature of eco-materials.

- **Embodied Energy:** The total energy used in a material's creation, transportation, and disposal is known as the embodied energy. The embodied energy of next-generation eco-materials usually is much lower than that of traditional materials like steel or concrete.
- **Circular Economy:** Moving beyond the traditional "take-make-dispose" linear model, a circular economy aims to keep resources in use for as long as possible, extract the maximum value from them whilst in use, and then recover and regenerate materials and products at the end of their time of use. Because they are recyclable, reusable, or biodegradable, eco-materials frequently help with this.
- **Resource Efficiency:** Resource efficiency is the process of producing building components with less energy and raw materials, which lowers the amount of waste produced during construction and deconstruction.
- **Indoor Environmental Quality (IEQ):** Eco-materials frequently improve indoor air quality, thermal comfort, and natural light while also reducing the emissions of organic chemicals. This goes beyond their effects on the environment.
- **Ecosystem services and biodiversity:** Certain eco-materials, especially those that come from natural sources, can promote biodiversity.

1.2 What are examples of Next-Generation Eco-Materials?

Here are some prominent examples demonstrating the diversity and innovation in this field:

- **Mycelium Composites:** Materials grown from fungal root structures (mycelium) and agricultural waste. They are biodegradable, lightweight, fire-resistant, and have excellent insulating properties, making them suitable for insulation panels, bricks, and packaging.
- **Engineered Bamboo:** A rapidly renewable resource, bamboo can be processed into highly durable and strong structural elements, flooring, and cladding, offering an alternative to timber and steel.
- **Recycled Content Materials:** This category includes materials like recycled steel, recycled concrete aggregates, recycled plastics (e.g., for roofing tiles, insulation), and recycled glass. Utilizing waste streams reduces demand for virgin resources and minimizes landfill waste.
- **Bioplastics and Biopolymers:** Derived from renewable biomass sources (e.g., corn starch, algae), these plastics can be biodegradable or compostable, offering alternatives for insulation, pipes, or architectural finishes.
- **Self-Healing Concrete:** Concrete engineered with bacteria or micro-capsules that release healing agents when cracks appear, extending the material's lifespan and reducing maintenance needs.

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- **Cross-Laminated Timber (CLT):** An engineered wood product made by gluing layers of solid-sawn timber together. It offers high strength-to-weight ratio, excellent fire performance, and carbon sequestration benefits, enabling multi-story timber buildings.
- **Phase Change Materials (PCMs):** Substances that absorb and release large amounts of latent heat when they change phase (e.g., solid to liquid), helping to regulate indoor temperatures and reduce energy consumption for heating and cooling.
- **Hempcrete:** A biocomposite material made from hemp hurds (the woody inner part of the hemp stalk), lime, and water. It's lightweight, breathable, provides excellent thermal insulation, and sequesters carbon dioxide.

These materials are not just theoretical concepts; many are already being integrated into contemporary sustainable building projects, demonstrating their viability and potential to transform our built environment for the better (Popescu et al., 2024).

2. Execute – The Role of Augmented Reality in Next-Generation Eco-Materials

Augmented Reality (AR) is emerging as a powerful tool in the development and adoption of next-generation eco-materials, bridging the gap between innovative science and practical application. By enabling interactive visualization, simulation, and real-time data integration, AR enhances how researchers, designers, and industries understand the properties and performance of sustainable materials. From virtual prototyping to eco-conscious product design, AR not only accelerates innovation but also fosters greater awareness of environmental impact, paving the way for more informed decisions in creating a greener future (Wang & Li, 2020).

2.1 Specific features and types of AR Tools

An AR application for this purpose would be more than just a visualization tool; it would be a dynamic platform for discovery, design, and problem-solving. Key features and tools could include:

- **3D Model Visualization:** Learners can view and interact with 3D models of different eco-materials (e.g., cross-sections of mycelium bricks, detailed views of self-healing concrete, internal structures of lightweight bio-inspired panels). This allows for a deeper understanding of their composition and properties.
- **Simulations:** Simulate natural processes that inspire eco-materials. For example, visualize how cracks heal in self-healing concrete, or how a bio-inspired facade regulates temperature.

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- **Data Visualization Overlays:** AR can overlay real-time data or information on physical objects (e.g., a sample of bamboo) showing its tensile strength, insulation value, or embodied energy.
- **Virtual Tours:** Take virtual tours of existing sustainable buildings that utilize next-generation eco-materials, highlighting specific applications and their benefits.

2.2 Real studies and practical exercises

Meaningful integration of AR in hands-on learning is already happening globally, particularly in fields like environmental and urban education. These examples demonstrate how AR can move students beyond passive observation and into active, creative problem-solving inspired by nature.

Students at a secondary school in Singapore participated in workshops focused on biomimicry in architecture. Using an AR application, they could scan natural objects (e.g., a leaf, a bone) and see augmented information about its structural properties and potential architectural applications. They then used AR to overlay virtual bio-inspired facade designs onto miniature building models, receiving immediate visual feedback on how the designs could improve energy efficiency (Tan & Lim, 2021).

These examples demonstrate how AR can transform traditional learning activities into immersive, data-rich, and highly interactive experiences, bridging the gap between theoretical knowledge and practical application, and empowering students to engage with real-world environmental issues.

3. Enhance – AR for Deeper Learning and Engagement

3.1 Examples of Useful AR Apps and Tools

Various AR tools can significantly enhance the learning experience for ecosystem restoration by providing immersive and interactive ways to explore complex environmental concepts. Here is an example:

Delightex (CoSpaces Edu):

[Delightex]() allows users to create interactive 3D virtual worlds and then experience them in augmented reality or virtual reality. It features a drag-and-drop interface and a visual block-based coding language (CoBlocks), making it highly accessible for students and teachers with no prior coding experience. It offers a free version with core functionalities. Students can design and build their own virtual ecosystems,

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simulate environmental changes, and visualize restoration efforts. Its creative freedom empowers students to become content creators, not just consumers.

3.2 Practical Suggestions for Integration into the Learning Experience

Gamified learning environments or interactive 3D virtual worlds can challenge students to explore green infrastructure like new more sustainable eco materials. This makes learning about urban design both fun and informative.

Exercise: "Mission Sustainable" AR App

In this interactive AR experience, students take on the role of sustainability innovators. Using their devices, they explore outdated building materials in a virtual environment, such as concrete blocks, plastics, or steel and swap them with next-generation eco-materials designed to reduce waste, lower emissions, and save energy. Each choice impacts the future of the structure, challenging students to think critically about environmental trade-offs and the role of innovation in construction. The goal is to rebuild history with smarter, greener solutions one material at a time.

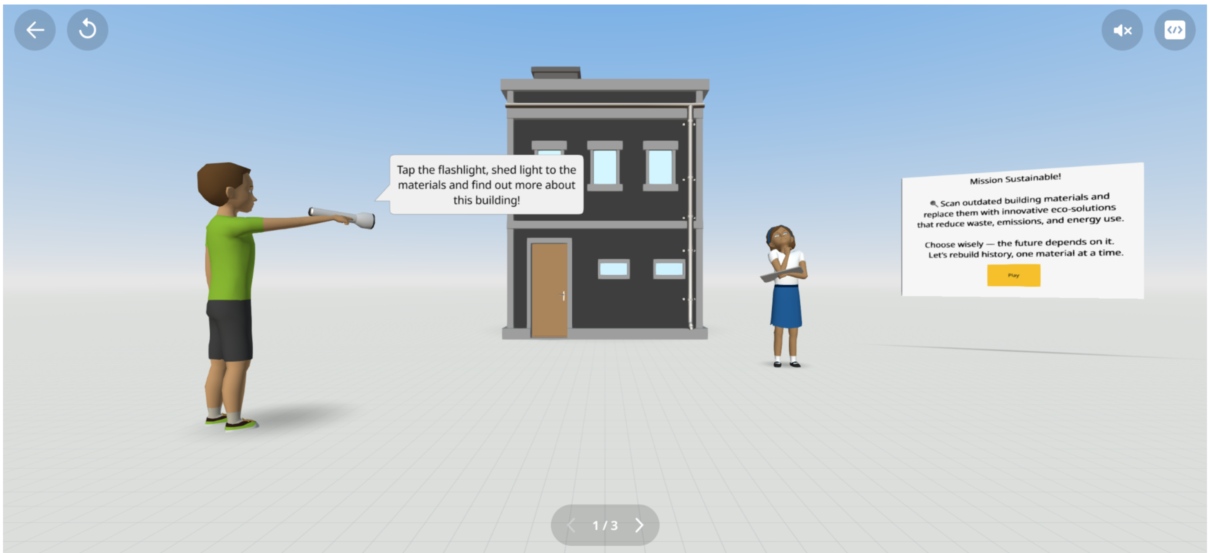

Image 2. "Mission Sustainable" AR App

By thoughtfully integrating AR into the curriculum, educators can create dynamic, immersive learning experiences that not only strengthen students' connection to eco-materials and biomimicry in construction, but also empower them with the knowledge and tools to become active participants in environmental stewardship.

Conclusion

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This learning unit has guided you through the fascinating world of Next-Generation Eco-Materials and their pivotal role in shaping sustainable architecture. Technologies such as Augmented Reality improve our capability to comprehend, visualize, and interact with these essential concepts, converting abstract notions into concrete, interactive experiences. By visualizing invisible processes, simplifying complex data, and fostering active engagement, AR tools empower learners to not only comprehend the principles of sustainable architecture but also to envision and design the eco-conscious buildings of tomorrow. This blend of cutting-edge materials and immersive technology paves the way for a generation of architects, engineers, and citizens who are equipped to build a more sustainable future.

Phase	Description
Explore	- Research and Discovery: Introduce environmental challenges of conventional building materials (concrete, plastics, steel) and present next-generation eco-materials (bioplastics, hempcrete, mycelium composites, recycled aggregates, phase-change materials). Highlight how these materials reduce waste, emissions, and energy use.
	- Content Development: Provide accessible resources (short articles, videos, infographics) comparing traditional and eco-materials. Focus on lifecycle impacts, carbon footprint, recyclability, and innovative applications in modern architecture.
	- Needs Analysis: Assess students' prior knowledge of building materials, sustainability, and innovation in construction to tailor the AR activity and ensure accessibility.
Execute	- Curriculum Implementation: Link eco-materials to broader sustainability and innovation goals in architecture, showing how design decisions impact climate change mitigation and resource conservation.
	- Interactive Exercises: Analyze real-world case studies of innovative buildings that have successfully implemented eco-materials, comparing their AR design choices with actual architectural examples.
	- Feedback Collection: Use class discussions or digital surveys to evaluate their reasoning and understanding of material choices.
Enhance	- AR Integration: Use AR App "Mission Sustainable" to visualize how eco materials transform both the building and its environmental performance.
	- Interactive Learning: Students explore outdated building materials in a virtual environment and **swap them with eco-material alternatives**. Real-time feedback shows environmental trade-offs, energy savings, and structural impacts.
	Gamified Content: - **Quests and Levels**: Correct quiz answers and optimal material choices unlock progression.
	AR-Based Assessments: Evaluate student learning through their material selections, quiz results, and the sustainability performance of their AR-based building choices.

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