What if self-evolving microhabitats restored biodiversity in urban spaces while adapting to changing needs?

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Living Gardens

Within Reach | **Transitional** | Visionary

4D-printed microhabitats in gardens dynamically respond to environmental and biodiversity changes, creating ideal conditions for plants, insects and microorganisms to grow together naturally.

UNCERTAINTIES

Nature, Technology

MEGATREND (Most significant)

Evolving Ecosystems

TRENDS

Biomimicry
New Materials
Restoration

TECHNOLOGIES

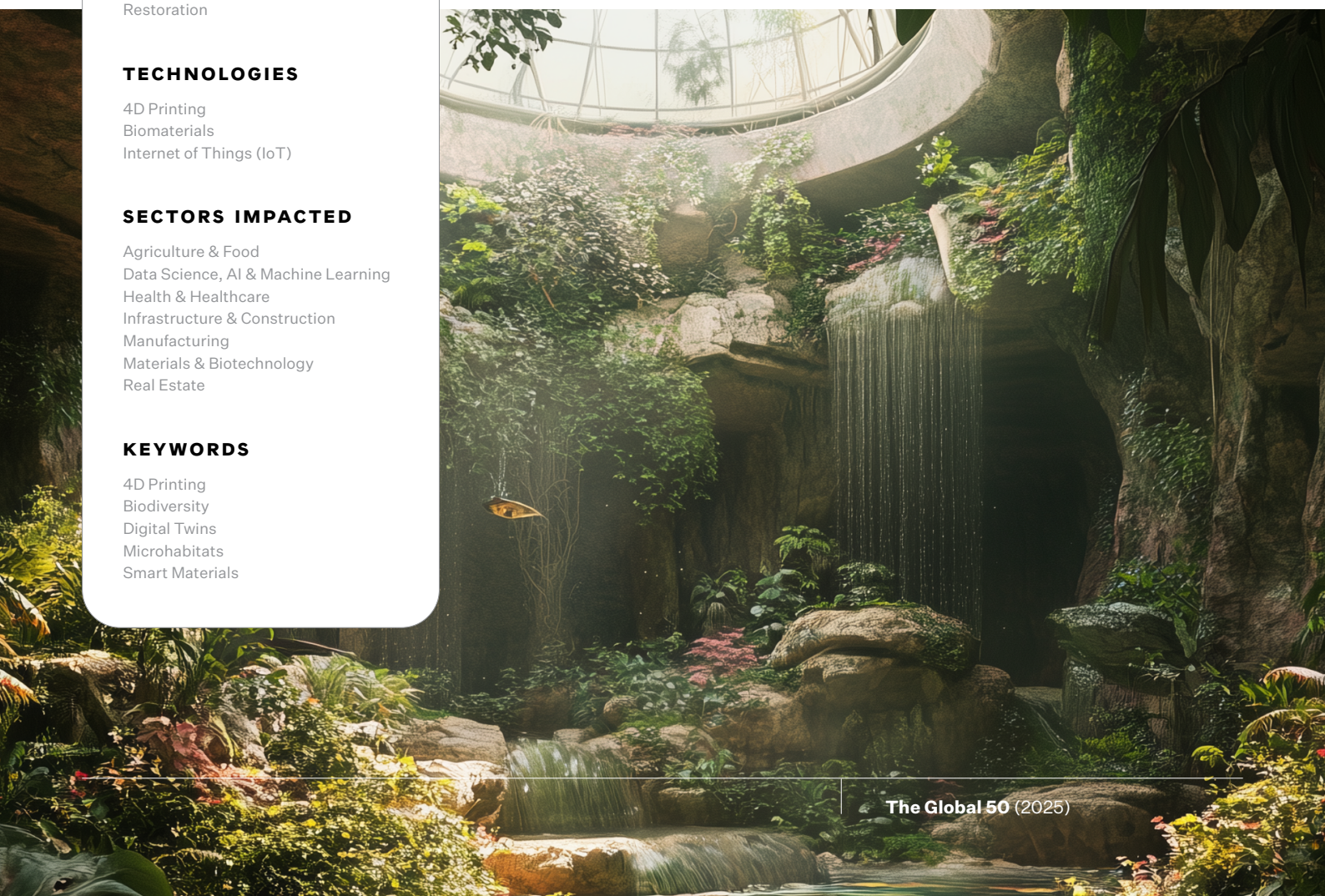
4D Printing
Biomaterials
Internet of Things (IoT)

SECTORS IMPACTED

Agriculture & Food
Data Science, AI & Machine Learning
Health & Healthcare
Infrastructure & Construction
Manufacturing
Materials & Biotechnology
Real Estate

KEYWORDS

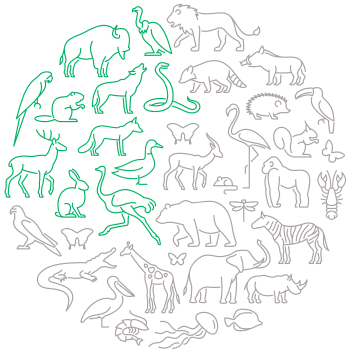
4D Printing
Biodiversity
Digital Twins
Microhabitats
Smart Materials



WHY IT MATTERS TODAY

69%

average decline in terrestrial wildlife populations since 1970, marking biodiversity loss as a pressing environmental crisis alongside climate change



Biodiversity loss is a critical global issue. It is accelerating at an unprecedented rate, with profound implications for ecosystem stability and human well-being. Around 1 million species are currently threatened with extinction, with the number rising over time.[655] Recent data from the Living Planet Report show a 69% average decline in terrestrial wildlife populations since 1970, marking biodiversity loss as a pressing environmental crisis alongside climate change.[656] Among environmental risks in the next ten years, biodiversity loss ranks as the second most severe threats.[657]

Declining urban green spaces are further contributing to biodiversity loss. Currently, over 56% of the world's population live in urban areas,[658] which is contributing to a significant decline in urban green cover.[659] Urbanisation is impacting biodiversity conservation, the connection between humans and nature, and the health and well-being of both wildlife and people. The restoration of urban green spaces, which is crucial for strengthening ecosystems, has never been more urgent. With each degree of global warming, the risk of species extinction grows larger.[660] The relationship between biodiversity and climate change is reciprocal: if one suffers harm, so does the other.

4D printing – that is, 3D printing that incorporates smart materials that respond to stimuli and cause the 3D object to change over time – emerged in 2013.[661] Key applications of 4D printing include soft robotics, toys and microtubes, and contexts that require bending, twisting, lengthening and moving in wave-like patterns as a result of environmental changes.[662] Future applications include self-healing bridges and expandable infrastructure, self-tailored clothing and adaptive shoes, on-demand prosthetics and smart implants, and even bone and tissue growth in regenerative medicine.[663] As a precursor to 4D printing, the global 3D-printing market was valued at $20 billion in 2023 and is expected to expand at a compound annual growth rate of 23.3% to $88 billion by 2030.[664]

THE OPPORTUNITY

BENEFITS

Enhanced biodiversity; increased ecosystem resilience; enhanced air quality; ecological restoration.

RISKS

Dependence on technology for ecosystem conservation; unintended consequences for microorganisms; cyberbiosecurity; cost.

4D-printed microhabitats[665] enhance urban and rural gardens, creating thriving natural ecosystems.[666] These microhabitats use the Internet of Things (IoT) sensors and edge computing to monitor the environment and adapt in real time to changing conditions.[667] Inspired by biomimicry, these microhabitats respond to environmental triggers such as light, heat and pH (acidity) levels.[668] Over time, these microhabitats integrate with the existing garden environments, helping to spread healthy ecosystems naturally.

Constructed using 3D printing from smart materials such as shape-memory polymers,[669] these structures – designed to mimic natural elements such as plants, rocks and stones – can alter their form and characteristics in response to their surroundings, enabling them to dynamically adapt to shifting conditions,[670] making them 4D. The microhabitats also capture and store carbon dioxide,[671] collect rainwater to hydrate soil, and regulate temperature for microorganisms through shading.[672] In addition to microorganisms, the microhabitats support pollinators, which together with microorganisms are crucial for supporting local food systems. The microhabitats also play a role in combating deforestation and restoring biodiversity.