DeMorph: Morphing Devices Functioning via Sequential Degradation

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ABSTRACT

While it may initially seem counterintuitive to view degradation within an operating system as advantageous, one could argue that, when intentionally designed, the controlled breakdown of materials—whether physical, chemical, or biological—can be leveraged for specific functions. To apply this principle to the development of functional morphing devices, we have introduced the concept of **"Degrade to Function" (DtF) [16]**. This concept is aimed at creating eco-friendly and self-contained morphing devices that operate through a series of environmentally-triggered degradations. In this demonstration, we elucidate the DtF design strategy and present five application examples across a range of ecosystems.

CCS CONCEPTS

• **Human-centered computing → Interactive systems and tools**.

KEYWORDS

Shape-changing Interface, eco-friendly, sustainability, degradation

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1 DEGRADE TO FUNCTION STRATEGY

Sustainable design has emerged as an increasingly significant theme within the field of Human-Computer interaction (HCI), in material exploration, interface design and device fabrication [1, 8, 12, 17, 20, 22–24]. While many strategies have contributed towards mitigating resource-related challenges, they alone cannot fully resolve waste-related issues. Consequently, there is a growing interest in leveraging the (bio)degradability of materials at their end-of-life stage, spotlighting it as a potent avenue for sustainable waste management [1, 2, 19].

While material degradation is commonly viewed as detrimental to system operation and ideally only occurs at the end-of-life [9], there are numerous cases where the physical, chemical, or biological breakdown of materials is intentionally leveraged for a specific function. For instance, fuses safeguard against electrical overloads [4], seed capsules of the squirting cucumber burst to release seeds [6]. Adopting a similar strategy, Functional Destruction [3] suggests that material destruction can be strategically used to fulfill specific objectives of the transient electronics. However, although electronics can incorporate degradable materials, they typically still depend on a mix of conventional components such as semiconductors and batteries for functionality [11, 21]. Yet, the realm of morphing devices has seen the rise of electronic-free systems as a complement. These systems often utilize innovative materials that can respond to various stimuli to create functional mechanisms [5, 10, 14, 15, 25]. Nonetheless, these advanced materials can be expensive and complicated to manufacture. They may also require specialized recycling processes, resulting in high embodied energy and carbon dioxide emissions throughout their lifecycle [11]. This could compromise efforts to achieve sustainability goals.

Inspired by these precedents and aiming to address existing gaps, we explore the concept of **"Degrade to Function" (DtF) [16]**. We investigate natural materials that exhibit different rates of degradation under varying environmental conditions. By strategically integrating these degradation characteristics with real-world environmental condition changes, we aim to design autonomous morphing devices capable of sequential deformations to achieve specific functions. We hope this research spurs the development of sustainable morphing devices that are not only environmentally friendly but also versatile in their applications, particularly in ecology-related scenarios.

2 APPLICATION EXAMPLES

In this demonstration, we showcase five applications designed under the DtF design strategy (Fig. 1). These examples span various ecosystems and address real-world environmental issues, including:

- Acidic Soil Monitoring and Rehabilitation: A device with a magnesium foil "sensor" and $CaCO_3$ couriers, designed to neutralize soil acidity and release beneficial microbes, helps restore acidic soils.
- Desertification-Assisted Governance: Engineered anemochorous seeds with temperature-sensitive beeswax bonds and water-absorbing alginate couriers are used for effective wind dispersal and anchoring in desert environments for.
- Wildfire Detection and Monitoring: A device uses a carnauba wax constraint that melts at high temperatures to release wooden fly sensors for early-warning and data collection during wildfires.
- Forest Feeder and Seeder: An automatic feeder and sower device uses mold-activated opening mechanisms and synthetic

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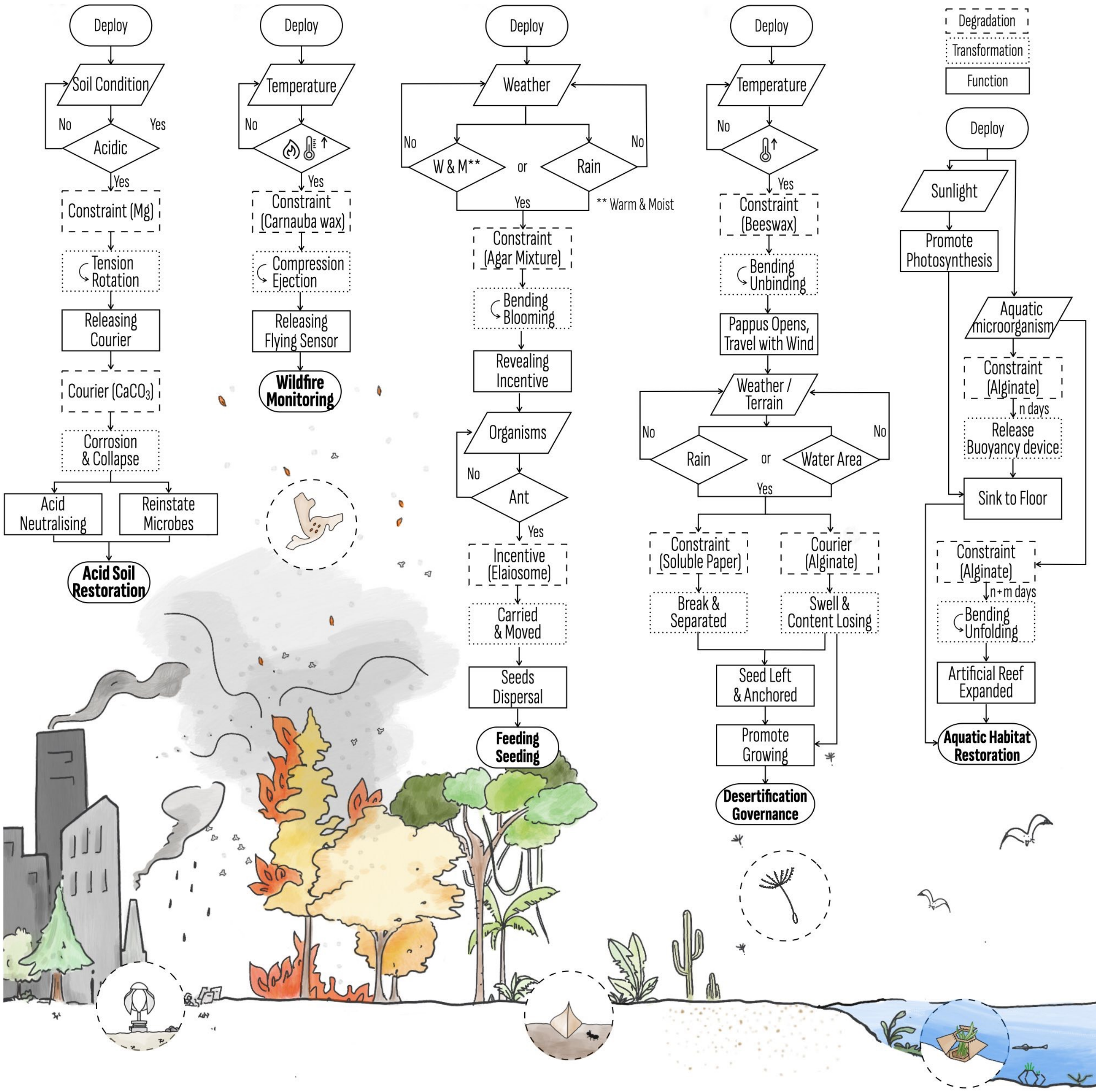

Figure 1: An overview of five examples of Degrade to Function applications across various ecosystems.

elaiosomes to attract ants for seed dispersal in forest restoration efforts.

- Aquatic Habitat Restoration: An artificial reef designed for delayed settling and autonomous deployment incorporates buoyancy devices and alginate constraints. These features not only facilitate seagrass germination but also create a sustainable habitat for diverse marine life.

3 CONCLUSION

The DtF strategy enables self-sustaining morphing devices activated by environmental degradation triggers, opening up diverse possibilities. Future directions could include developing design tools [7, 13, 26] with extended material libraries, conducting more long-term field tests to verify application examples [18], and exploring additional potential applications.

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