Biodegradation in Design Process

Digital building catalog for bio-inspired design proposals

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Through the incorporation of fungal biodegradation processes into architectural design, a novel approach to sustainability is possible, which goes beyond the selection of materials and growth processes and enables insights from natural decomposition. While biodegradable materials are increasingly studied, the potential of biodegradation itself to shape design remains largely unexplored. Although the biodegradation process is seen as the final stage of design, the existing knowledge of structural deformation in nature could be an inspiration for the design process in the early stages. This study analyzes the structural transformations of five fungal species during biodegradation in mesh-like frameworks as a basis for future research. This research involves a literature review, experimental analysis, and digital catalog development, resulting in MyCo-Design, a platform that documents species-specific biodegradation data. Structural changes such as shrinkage, curvature, stiffness reduction, and volume decrease were captured through photography and 3D scanning techniques, providing a resource for bio-inspired designs. MyCo-Design platform provides designers with information by species, structural forms, and degradation parameters to use as inspiration in the early stages of their design process. This platform features an AI-powered interface component that enables users to generate visuals based on design prompts inspired by experimental observation data. During the testing process, the platform showed potential in inspiring structural solutions based on biodegradation observation. The findings of the study highlight the potential to generate circular inspiration in the early stages of design through a tool created at the intersection of nature, humans, and artificial intelligence.

Keywords: *Fungal Biodegradation, Bio-Collaborative Design, AI-Inclusive Design, Bio-Inspired Templating, Design Catalog*

INTRODUCTION

The growing concern about environmental issues has led to increasing importance being placed on sustainable design, aiming to balance aesthetic appeal, functionality, and ecological responsibility. In architecture, the integration of sustainable practices has mainly focused on selecting appropriate materials and understanding the structural dynamics of emerging ones. In the context of design and biodegradation, most studies have concentrated on the production aspect, with relatively limited attention directed toward the degradation process. A growing body of research explores the potential of biodegradable materials derived from natural sources such as fungi, algae,

cellulose, bacteria, and other living organisms (Mukherjee et al., 2023). Examples include Martin Margiela's collection in collaboration with a microbiologist, where living agents caused unexpected changes in the garments (La Maison Martin Margiela, 1997); The Living's HyFi pavilion, constructed with bricks grown from fungal mycelium (Almpani-Lekka, 2021); Neri Oxman's Aguahoja project, which uses water-based materials like chitosan and cellulose to create biodegradable structures (2014); and Magnus Larsson's Dune project, which employs microbial deposition to create habitable structures in dunes (Pawlyn, 2016). Despite these advancements, a significant gap remains in utilizing biodegradation processes as a data source for architectural design.

It is possible to incorporate biodegradation into the design process itself, rather than merely considering it as a final stage. Ammala et al. (2011) define biodegradation as the breakdown of organic materials by microorganisms under certain environmental conditions. It can also be considered the last stage of the design process, where it reconnects with nature. The biodegradation processes of many living organisms can inform the design process in two ways: as an environmentally focused solution and as a source of inspiration for artistic and material exploration (Song et al., 2024). The use of biodegradable and living materials introduces unpredictability, allowing a departure from traditional design paradigms. As these materials undergo natural changes—decomposing, growing, or mutating—they can facilitate a dynamic and evolving design process (Anjimoon et al., 2024). In this context, living organisms such as fungi, bacteria, and algae play a key role in material breakdown. Fungi have shown remarkable abilities to decompose organic matter while creating complex structural formations (Bravery et al., 2020). The changes such as shrinkage, hardening, and fractal-like growth patterns can provide new cues for adaptable and flexible structures.

Fungi have long attracted interest, and many mathematical models of their growth and function exist in various disciplines. While the field of mycology already investigates these behaviors, in architectural design, fungi's structural deformations especially in mesh-like formations offer new inspiration. Most studies examine fungal growth structurally, but there is a gap in analyzing the structural aspects of biodegradation and converting them into design data. This gap presents a compelling opportunity to explore how the structural characteristics of specific species can inspire sustainable design innovations. The selected species include Suillus mediterraneensis (triangular mesh structure); Agaricus bisporus (linear structure); Pleurotus ostreatus (three-dimensional growth); Hydnum repandum (dentate structure with spines beneath the cap); and Chanterelle cibarius (distinct coloration and linearity). This research aims to develop a collaborative methodology combining natural and artificial intelligence, inspired by the structural behavior of fungi during biodegradation. It digitizes the biological information of these species. Specifically, the research explores: "How can biodegradation processes be systematically integrated into the early stages of design to inspire structural form?" and "How can species-specific bioinformation serve as a template for design?" The biological degradation process is redefined as a productive design input. While conventionally seen as the final stage of a product's life cycle, this study shifts the perspective by using fungal degradation data, observed and recorded through 2D/3D structural deformation, as a basis for bio-inspired architectural concepts. Rather than focusing only on biodegradable materials, it emphasizes the structural changes during degradation, such as shrinkage, curvature, volume loss, and decreasing hardness, promoting a sustainability approach aligned with circular design principles that

embraces transformation as part of the design process.

The structural observations are transformed into a digital building catalog. The platform uses AI-powered generative design tools to provide early-stage design inspiration based on deformation processes, reducing reliance on trial-and-error methods in conventional design. Its purpose is to present an artistic and conceptual framework for architectural design, which can also be applied across scales, such as interior architecture, industrial design or fashion design. The study is structured into three main phases: identifying emerging patterns and gaps in the literature, conducting experimental analysis, and developing a digital building platform.

LITERATURE REVIEW

In recent years, significant advances in biodegradable materials derived from renewable resources have shown that they can effectively compete with the functionality and physical properties of traditional petrochemical-based materials (Fouad & Farag, 2020). These materials enable product biodegradation at the end of life, minimizing environmental impact. Silvia et al. (2023) highlight the rising importance of biodegradable polymers, their degradation processes, and the challenges to achieving true sustainability. The innovative use of biodegradable materials is transforming various design disciplines. For instance, Han et al. (2023) explore the intersection of biodegradation and smart technology in food safety through packaging that detects spoilage and extends shelf life. Aeby et al. (2022) detail the fabrication of printed humidity sensors made entirely from biodegradable materials such as shellac and egg albumin. The fashion industry has also begun integrating biodegradable materials to reduce its environmental footprint. Brands now use bioplastics in products like sunglasses and shoe soles. For example, Adidas introduced biodegradable midsole running shoes made from Mylo™, a mycelium-based leather substitute (Mihailovich, 2024). In architecture, biodegradable materials are increasingly applied in construction. Banyal et al. (2024) examine biodegradable nanocomposites for climate-specific building design. Bamboo and hemp concrete are being reintroduced as biodegradable, renewable materials suited for insulation and structural purposes, requiring minimal energy and degrading naturally after use (Vijayan et al., 2023). The concept of "living architecture" is also emerging, incorporating bio-based materials that can regenerate or decompose. Bio-bricks made from microorganisms and agricultural waste are used as sustainable alternatives (Stefanova et al., 2020). Mycelium-based composites, grown on agricultural waste, offer comparable thermal, acoustic, and structural performance to hydrocarbon-based materials (Alemu et al., 2022). Mohseni et al. (2023) explored 3D printing with these composites, while Sydor et al. (2021) emphasized their aesthetic and ecological value in interior design and art, noting their use in furniture, panels, and claddings. While literature on biodegradable materials in design is expanding, there remains a notable gap regarding the structural transformations that occur during biodegradation and how these can inform and inspire the design process.

METHODOLOGY

As in nature, the biodegradation process can be part of a circular system in design. Based on this approach, the authors focused on using biodegradation as inspiration for designers. A methodological approach integrating nature and artificial intelligence was employed to examine the structural behavior of fungal species during biodegradation and translate these findings into a design proposal. The study emphasizes the importance of collaboration between nature, humans, and AI in the design process. While literature review and experiments provide insights

into natural processes, analysis and synthesis of findings are based on the authors' observations. The integration of an AI engine with image-generation capabilities further highlights the role of artificial intelligence in generating potential design solutions. The methodology consists of three main phases: (1) a literature review to define the framework and identify the gap; (2) experimental analysis; and (3) the integration of findings into architectural design proposals through a digital building platform (Figure 1). This platform acts as an interface that uses structural observations as text-based data during the deformation process and enhances the design workflow through AI-driven image generation.

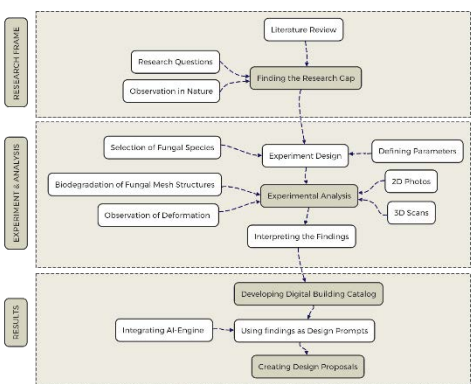


Figure 1
Flowchart of the study methodology

The literature review identified gaps in existing research, noting that most studies focus on the growth and material applications of biodegradable organisms rather than their degradation processes. This highlighted the potential of considering biodegradation as a generative phase rather than merely the final stage of a material's life cycle. After the research frame was identified, for the experiment phase, five fungal species were selected based on their different structural characteristics and biodegradation potential. These species exhibited diverse deformation behaviors, such as shrinkage, stiffness reduction, and volume decrease, which were recorded through photography and 3D scanning techniques. This documentation provided valuable insights into structural transformations during biodegradation and formed the basis for generating design prompts. The final phase involved the development of the MyCo-Design platform, a digital building catalog that organizes experimental findings into inspirational prompts for the image generation tool. For this, the Bubble.io platform was used as no-code development environment that enables users to build fully functional web applications without writing code. During the catalog's development in Bubble.io (2025), the interface was designed, and the experimental data of five fungal species were processed. These data types included both images and text-based information related to the biodegradation process. Following the interface design and database setup, workflows and actions on the website were defined. Bubble.io also provides API integration functionality, allowing the application to exchange data with external services. Using its API Connector (Figure 2), the platform was integrated with DALL·E 3 (OpenAI, 2025) to enable AI-driven

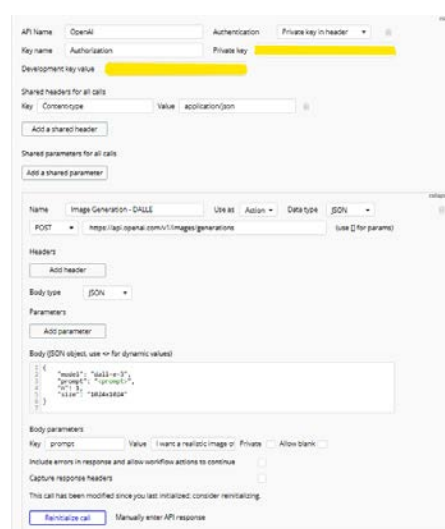


Figure 2
Connection of DALL-E 3 through API Integration

image generation based on structural data derived from the biodegradation process.

This integration enabled the application to call the DALL·E 3 API, generating images based on specific prompts provided by the user. The image generation section of the platform allows users to enter experimental observations as design prompts, linking their input directly to the image generator. The digital building platform provides a systematic framework for accessing and utilizing bio-inspired design proposals. It was developed to demonstrate the potential of using biodegradation data in early design stages and proposes enhancements for future iterations. This approach enables the documentation of biodegradation processes of various living species, including fungi, within a database, offering inspiration across diverse design contexts.

Experiment on Fungal Species

In this study, five fungal species were selected for experimental design. Suillus mediterraneensis is characterized by a convex or slightly depressed cap with a sticky surface and spongy pores that change from yellow to olive brown as it matures (Ait Hamadouche, 2024). Agaricus bisporus, widely cultivated and consumed, has a smooth cap that flattens with maturity, shifting in color from white to brown, and gills that turn from pink to dark brown (Zhang et al., 2018). Pleurotus ostreatus features a convex to fan-shaped cap, varying from whitish to dark bluish-black, and becomes less moist over time (Jang et al., 2003). Hydnum repandum (hedgehog mushroom) displays a cap that shifts from convex to wavy with age and a velvety surface in pale orange to cream tones (Bhambri et al., 2022; Feng et al., 2016). Chanterelle cibarius (golden chanterelle) has a funnel-shaped, velvety cap that becomes sticky when wet, aiding moisture retention, with false gills underneath that support spore distribution (Kuo, 2015; Muszyńska et al., 2016). During the experiment, deformations were observed in the mesh structures of these fungi after three months of sun exposure (Table 1). The focus was on two-dimensional structural changes occurring during drying and deformation, influenced by environmental factors such as temperature, sunlight, moisture levels, and water retention capacity. Each fungal species exhibits a unique deformation process due to structural and dimensional differences. However, some common deformational characteristics were observed across all five species. Initially, the porous structure beneath the cap consists of regularly repeated geometric forms in a homogeneous pattern. Over time, through the deformation process, this structure becomes amorphous and gradually loses its rigidity.

As the fungi mature, they go through deformation phases characterized by irregularities and fragmentation on their surface. The structural forms of the fungi have specific characteristics such as rigidity, tensility, stress, and strength. A reduction in the mesh volume was observed in each one until the final stage of deformation. As the points joined, the lines transformed into curves. At certain points, the curved lines undergo deformation and distortion, integrated (Figure 3).

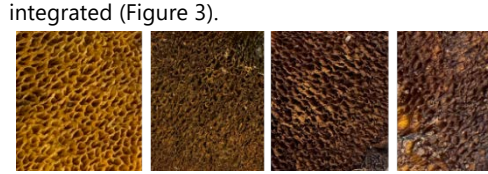


Figure 3
Example of the deformed mesh structure of Suillus mediterraneensis, illustrating the transformation from a regular geometric pattern to an amorphous form.

Structural differences led to low rigidity and increased stress. During deformation, the mesh structure initially experienced rising tension, which gradually decreased. Shrinking of the mesh's linear elements caused the surface curves to draw closer, resulting in reduced rigidity and volume. However, stress levels and resistance varied among species. As the curves merged, the curvature of each cell boundary increased. In addition to two-dimensional deformation, three-dimensional formal transformations were observed in fungal volumes (Table 2).

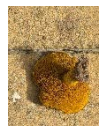
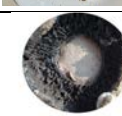
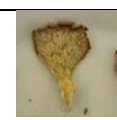
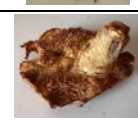
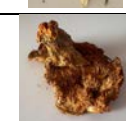
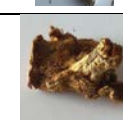
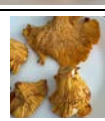
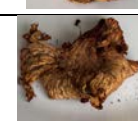
	First Phase	Deformation Phase	Deformation Phase	Deformation Phase	Last Phase
Suillus mediter-raneensis					
Agaricus bisporus					
Pleurotus ostreatus					
Hydnum repandum					
Chanterelle cibarius					

Table 1
Procedural photographs displaying the structural deformation process of fungal species.

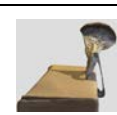
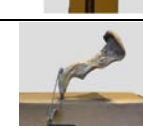
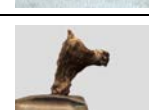
	Top View	Front View	Side View
Suillus mediterraneensis			
Pleurotus ostreatus			
Hydnum repandum			
Chanterelle cibarius			

Table 2
3D scans displaying the structural deformation of fungal species.

Common stages included the bending of rigid, upright structures and their transition into amorphous forms. Shrinkage was evident in all fungal samples, which darkened in color and became more fragile over time. Fungi that were initially soft and flexible became brittle by the end of the deformation process. Shrinkage occurred in both mesh and solid mass areas due to the gradual withdrawal of air and water from porous parts under sun exposure. Beyond drying, structural changes such as warping, brittleness, shrinkage, and darkening occurred, influenced by variations in sunlight angle and intensity.

Digital Building Platform: MyCo-Design

As the final stage of this study, the digital platform MyCo-Design was developed to transform the biodegradation process, typically seen as the end of a product's life, into a design input (Figure 4). The platform draws on experimental data to support the development of bio-inspired design proposals through collaboration between nature, humans, and artificial intelligence (Figure 5). It communicates fungal behaviors during degradation (such as shrinkage, amorphization, volume loss, color change, and curvilinearity) to designers through images, text, and 3D scans. Users can view these 3D models via Sketchfab integration (2025). Currently, the database includes five fungal species, with plans to expand both the number and diversity in future studies. Developed in Bubble.io (2025), the platform features a section where users input deformation-inspired prompts connected to DALL·E 3 via OpenAI's API Connector (2025) (Figure 6). This AI extension visualizes user ideas inspired by observed biodegradation, offering a narrative of evolving formal qualities such as texture, surface variability, and structural transformation. These stages can serve as design inputs for architectural concepts that explore the relationship between form, material aging, and surface behavior.

Finally, a user test session was conducted with five participants from the design field to evaluate the platform's usability and functionality. Based on feedback, key areas for improvement were identified: enhancing user interface interaction, integrating AI for autonomous analysis, and developing a design-oriented prompt system to accommodate varied user profiles.

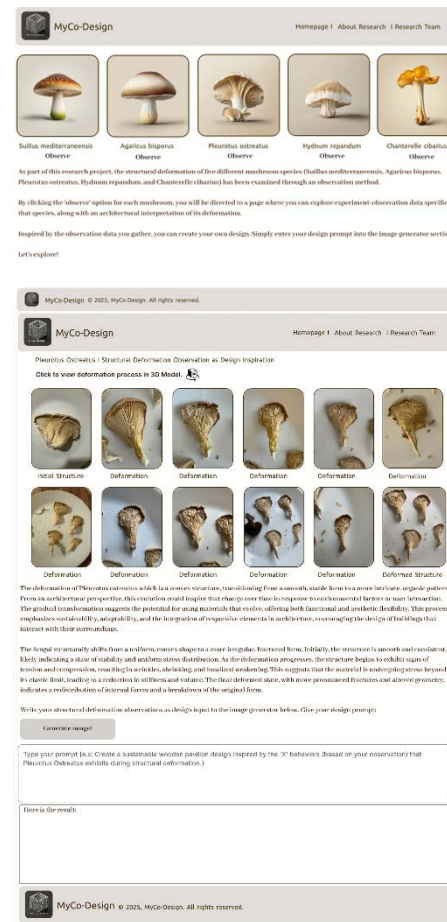


Figure 4
MyCo-Design/ Homepage.

Figure 5
MyCo-Design/ Observation page of Pleurotus ostreatus.

Figure 6
Visual creation steps (1,2,3) in the design process by entering the user's prompt into the image generator inspired by the deformation process of fungi.

CONCLUSION

This study emphasizes the missing stage of returning to nature in the architectural design process, demonstrating that it can be transformed into a comprehensive building catalog via a digital platform integrating nature, human input, and AI output. It offers insights into how these elements can collaboratively support sustainable design by bridging natural processes with architectural practice. The research identifies several areas for further development. First, it calls for a more extensive and detailed database capturing various natural processes, particularly biodegradation, to better inform design decisions. Second, the platform's user interface should be improved to enhance usability and provide a more intuitive experience. Enhancing the performance of the AI engine is also crucial to ensure it generates contextually relevant and accurate proposals. User testing with five participants revealed the need for more interactive AI support in monitoring experimental data and prompt entry. It also highlighted the importance of generating more detailed, visually based structural outputs. These developments would allow the platform to evolve from early-stage inspiration into a tool capable of delivering design proposals at multiple scales. In conclusion, this study demonstrates the potential of integrating natural systems, human creativity, and AI in architectural design. While promising, further refinement in database scope, user interaction, AI functionality, and design output quality is essential to fully realize its contribution to sustainable architecture.

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