Augmented (mate)Reality: Exploring hybrid materials from machine learning to physical production

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Abstract. While cities face daily challenges from emerging climate patterns, there is a need to rethink how we live and build our urban environments with a new agenda. Existing city networks are filled with obsolete buildings whose structures and materials require replacement, adaptation, or reinforcement. Biomaterials, which have emerged over the last decades, offer an exciting opportunity while questioning the lifespan of materials and the need for temporary constructs. Although significant research has been conducted, the main issue of scaling remains. Whether used as a growing material on a traditional substrate, as an autonomous bio-membrane, or as a structure attached to existing infrastructure, it is crucial to explore advanced techniques for amalgamating living and non-living matter and integrating past and post-fabrication processes. This paper presents work produced within the framework of an undergraduate design studio focused on applying hybrid materials for sustainable, data-driven design, inspired by machine learning (ML) text-to-image datasets.

Keywords: Machine learning, generative design, biomaterials, digital fabrication, climate change

1 Introduction

This paper presents a synergy between Artificial Intelligence text-to-image platforms and matter distribution. Material properties and dynamics are derived from an open-source dataset to reimagine patterns, textures, and structural relationships. The methodology is applied to urban skins and existing building facades within the city network. Cities are reshaping their boundaries through deep skins, which serve as thresholds between interior and exterior spaces, envisioned as a potential new public space network.

The work presented is the outcome of two design studio modules from a 2nd-year undergraduate program in Architecture and Environmental Design. Based on a data-driven design approach, the aim is to connect macro and micro scales through the application of environmental and contextual information in designing new hybrid material systems. Hybrids are created between organic and inorganic matter through a variety of combinations of conventional materials and biomaterials. Hybrid strategies are introduced to merge traditional techniques—both physical and digital—with advanced ML text-to-image/image-to-image tools, physical prototypes, and material experiments.

One aim is to explore new ways of material formation to enhance the performance of structures while attributing sustainability properties to traditional fabrication elements. It is also imperative to test new AI technologies within the educational agenda, question and renegotiate authorship, and set boundaries between copying and creative use and application.

1.1 Background

There has been extensive research on biomaterials, accompanied by significant criticism, mostly related to their scalability. Initial attempts to scale involved performative facades and column structures, which tested the integrity, connection to environment, and structural capacity of the materials.

From the *Photosynthetica Curtain* of Ecologic Studio to the *Indus Tile* by The Bartlett Bio-ID Lab and Shneel Malik, algae have been a prominent biomaterial used for bioremediation. In the first project, algae were combined with bioplastic sheets, while in the Indus Tile, algae were made into a paste and 3D-printed onto a clay pattern that would provide the path for rainwater circulation and detoxification (Malik et al., 2019). Pasquero et al. discuss the Urbansphere and human behavior in relation to other species, as well as an architectural symbiosis between buildings and biological growth (Pasquero et al., 2020). The hybridization of materials has begun to emerge; however, it still primarily involved repeating elements as tiles or tubes, and the membranes remain two-dimensional. While these membranes can provide cleaning functions, they act more as barriers rather than connectors between the interior and exterior of a building.

Prior to these examples, Cruz and Beckett conducted research on the application of organic growing matter on concrete. Their work focused on enhancing the environmental performance of building exteriors by modifying the microbiome to create a healthier indoor and outdoor environment (Cruz and Beckett, 2016). Marcos Cruz and Richard Beckett proposed a novel concept for building exteriors, termed the "tree bark" approach (Cruz and Beckett, 2016). This new interface between the exterior and interior incorporates engraving and sculpting techniques to expand the surface area, providing more space for bio-growth to occur. Another very interesting example is the Bacterial Cellulose Façade by the HBBE lab. (Morrow et al., 2023) However, the membrane is still flat and two-dimensional in its programmatic dimensions. It is not yet space; it is not yet inhabited; it is not yet scaled enough to be structural and host life.

Questions arise about the feasibility of scaling biomaterials for architectural structures, as suggested by Codgell Christina in her book *Toward a Living Architecture?* (Codgell, 2018). Recent research has begun incorporating bio-growth and microbial structures into larger constructions through material hybridization. Goidea et al. investigated the use of microbial structures in mycelium bio-composites (Goidea et al., 2020), while Dritsas et al. studied cellulosic bio-composites using wood fiber waste for sustainable fabrication technology (Dritsas et al., 2020). Both studies utilized 3D-printing as the primary fabrication technology, focusing on the construction of hybrid material filaments.

While there is already extensive research on Text-to-Image in architectural design and in architectural education, its use to drive material experiments and fabrication strategies is one of the aspects of originality of this research. Daniel Kohler in his work explores the concepts of connection or disconnection of architecture with nature and refers to the ability of generative models to imitate through the art of composition with an interest to the urban scale. (Kohler, 2024) The idea of a machine recreation of a natural element, its properties and attributes, both in macro and micro scale, through the selective assemblage of various captured instances is the main interest of this research.

2 Methodology

According to Maria Voyatzaki, quoting Henri Bergson, there is a significant relationship between matter and action (Voyatzaki, 2018). Materials are influenced by both their own dynamics and the actions of their users. Malafouris, in his chapter “At the Potter’s Wheel” (Malafouris, 2008) from the book *Material Agency* (Knappett & Malafouris, 2008), notes that materials like clay are deeply connected to memory and socio-cultural contexts. Materials are shaped by fabrication techniques, can be modified or "hacked," and are influenced by technological advances and evolving environmental needs. They reflect the desired outcomes of societies and the requirements for human shelter. AI big datasets now allow materials and structures to be re-imagined and activated through the collective selective intelligence of sporadic moments that can be fused “in a single, harmonious composition” (Carpo, 2022).

2.1 Hybridization

Hybridization is used as a concept for creating a new set of advanced, "hacked" materials by combining traditional materials, such as concrete or clay, with emerging (yet still in micro-scale) biomaterials, like mycelium, chitosan, or bacterial cellulose, aiming to scale up the process.

Hybridization is also used as a concept for mixed design methods, merging AI online platforms such as Midjourney with material experiments and prototypes. Through the data sets' information of these platforms, new combinations of materials are imagined along with a new set of geometrical, structural, and performative properties.

The application in an architectural context requires converting 2D images into a 3D digital model/environment and eventually into an assembly of physical building components. The studio's work explores this necessity by employing a mix of techniques, including text-to-image machine learning, 3D modeling, data/simulation-driven design using Rhino+Grasshopper+plugins (Ladybug+Honeybee, Culebra), Autodesk Maya displacement mapping, CNC molding, and 3D printing (Figure 1).

Students are instructed to use ML platforms to develop a material-driven approach across multiple scales (micro to macro). They select a hybrid of one biomaterial and one traditional material that would work as structural. Combinations and structural hierarchies are created. The micro scale is crucial for exploring material interfaces, state changes, and the geometric associations that ML platform's data attribute to selected prompts.

ML explorations are further applied to architectural and data scales (medium and macro) on a selected existing building, guided by environmental and other contextual data.

2.2 Site

The studio aimed to explore Deep Skins as inhabitable interfaces that redefine the boundaries between interior and exterior spaces in urban environments, focusing on enhancing environmental performance. The chosen site was Google Headquarters at Kings Cross, London, by Heatherwick Studio in collaboration with A10, AKTII, and Bjarke Ingels Group. This building, with its existing sustainability program, allowed students to question and reassess its skin and mass from a new environmental and material perspective. The site's proximity to the canal enables it as a biodiversity driver. Its proximity to leading infrastructure network nodes makes it an important location to analyze.

Figure 1. Concrete, cork and moss hybrid. CNC model for casting mold. Source: John Herrera, 2024.

2.3 From Macro to Micro Scale

The design studio project is divided into two stages/modules. In the first stage, emphasis is given on contextual and environmental analysis of the entire building and the adjacent surroundings. The building is seen as a mass within its environment and the analysis aims at exploring the capacities within an urban macro scale.

Following the analysis, the students are asked to develop environmental and design strategies in two parallel modes: physical and digital AI-based. This included a mass re-evaluation through concept models and a selection of materials for the envisioned hybrid, using the Midjourney platform for investigation. Following the amalgamation of the two approaches, students are asked to focus on a specific part of the building. They are to examine this section in greater detail, understanding the interaction between materials, the thickness of the skin, and the creation of space/interfaces between the interior and exterior.

2.4 Environmental Analysis and Building Performance

At the analysis stage, students are asked to perform a contextual and environmental analysis by selecting two specific urban themes, such as circulation, land use, history, materiality, green infrastructure, or building morphology, and two environmental themes, such as light/shadow analysis, air pollution, wind analysis, thermal analysis, acoustic analysis/noise pollution, geology/topography/ground porosity, or humidity levels/water circulation.

The collected data is communicated via 2D/3D drawings (maps on plan and sections). Working towards an evidence-based design, correlations of data/findings and overlaps of information lead to research conclusions related to the building mass of the Google Kings Cross building and the adjacent context. The collection of data is performed through on-site measurements and digital simulations. At this stage, students are introduced to software such as Rhino and Grasshopper, Ladybug for environmental simulations, and ML online platforms.

2.5 Mass re-evaluation

Based on contextual and environmental data and related conclusions, students are introduced to a mass redistribution workshop through concept models. The mass boundary of the Google building is questioned and retraced for optimal environmental and urban performance. Students develop a schematic massing proposal that defines a design strategy responding to the site's contextual and environmental features. The physical models are also blended with ML/AI methods for a reevaluation of the building mass and the boundaries/facades.

2.6 Skin space through material hybrids

In the next stage, advanced concepts of city skins are explored, creating new facades and hacking existing ones through a system of "material hybrids" that activate city elements (vertical and horizontal surfaces/autonomous or attached structures). The aim is to create interfaces that augment the existing urban fronts to tackle environmental issues and enhance the sustainability performance of the urban tissue. The relationship between existing façade networks is questioned and revisited through the application of new and advanced materials on an urban scale.

Skin is considered a three-dimensional element—a room, an interface that filters the interior to the exterior and vice versa—while accommodating the needs of people, animals, and infrastructure, becoming a connection, extension, or plug-in.

Students are asked to select a hybrid of materials that respond to their environmental theme and will form the basis of a design proposal. One list includes advanced materials: biomaterials/biopolymers such as cellulose, mycelium, plantation/moss/grass, algae, coconut mat, hemp, synthetic and natural fibers, loofah, chitin/chitosan, bamboo, linoleum, cork, straw, bioplastics, hydrogel, earth, and seaweed. The other list includes traditional materials such as concrete, wood, clay, metal, textiles, and weaving cables.

Students are asked to gather information on the material at both an urban and a material scale and use an AI platform to generate iterations and augment the design research on specific ideas. They will play with materiality inputs, either in the form of images or text, exploring hybrid conditions and the variability of multiple scale applications. AI/ML will also be used to revise the line of the skin and its three-dimensionality, and consequently, the relationship between interior and exterior.

2.7 Text-to-Texture / Physical prototyping

ML platforms are used to explore new patterns of material distribution and new interface relationships between materials. Selecting a smaller part of the building skin allows for a detailed exploration of its texture, depth, and spatial attributes within the urban environment. Autodesk Maya displacement mapping is used to convert images to geometry. The final stage involves translating these material textures and interfaces into physical prototypes, experimenting with the selected material hybrids. (Figure 8)

3 Results

The final outcomes include 40x40cm constructs, as well as 3D and 2D visualizations of the application on an urban skin/facade based on data simulations. Physical prototypes are also tested for their environmental performance.

3.1 Mycelium, hempcrete and plant growth

The first material hybrid exploration started through a physical concept model investigating porous skin transversing in patterns the whole building creating cavities that would be used as a three-dimensional skin that provides space and breathing properties. The materials explored were mycelium and hempcrete (Figure 2). The hybrid was explored through AI text-to-image technique with one of the Prompts being: "*Mycelium bricks intricate network cladding on structure, with additional plant overgrowth and dangling plants such as pothos, spreading like a disease, dystopia*". Following Midjourney experiments, the evolving patterns were physically reproduced through material prototypes. The fabrication process involved the following steps: A mixture of hemp and mycelium was initially prepared, and flour was added to initiate mycelium growth. The mixture was then placed in a mold and shaped manually. The mold was wrapped in plastic wrap with some holes poked in it and stored in a warm place (22-24°C) for about 5 days. Afterward, the structure was removed from the mold, left for an additional 2 days, and then baked for 3 hours at 70°C.

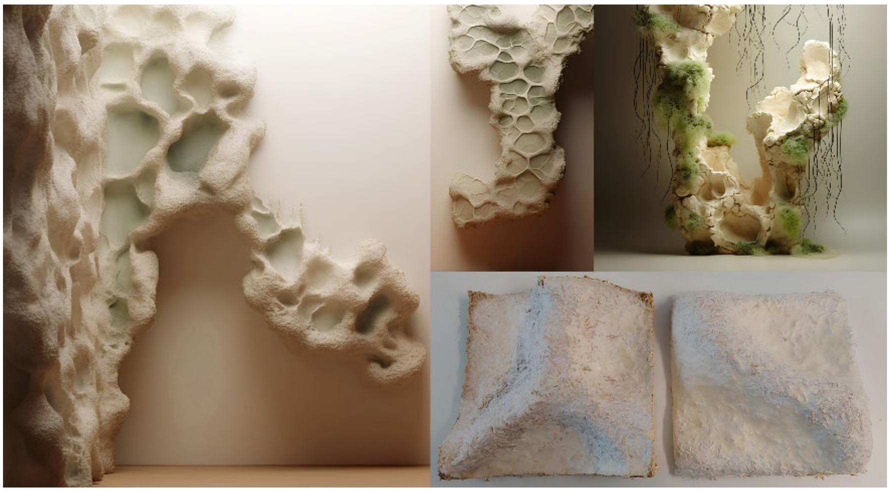

Figure 2. Mycelium, hempcrete and plant growth. Source: Gaia Spinoso, 2024.

3.2 Chitosan / rammed earth hybrid structure

Another hybrid material/AI experiment was conducted using a combination of chitin and rammed earth. Through reverse engineering of text-to-image outcomes, new prompts were created to re-elaborate on the chitin structure pattern (Figure 3).

The first material samples included tests of chitosan with many different secondary materials: a.) Chitosan and alginate solution b.) Chitosan solution over moss c.) Chitosan with glycerin d.) Chitosan and high concentration of alginate e.) Chitosan yarn with glycerin f.) Chitosan yarn without glycerin g.) Different concentrations of chitosan h.) Chitosan with low concentration of tea leaves i.) Chitosan with high concentration of tea leaves j.) High concentration of chitosan on bubble wrap dried k.) Low concentration of chitosan sheet dried (Figure 3). Chitosan was tested in hybridization with sand, clay soil and water to create a rammed earth compound. Various tests with different percentages were conducted to assess durability, strength, plasticity, and water resistance.

3.3 Seaweed / hydrogel hybrids

Another material hybrid was the combination of seaweed and hydrogel. Experiments with Midjourney suggested pliability, transparency, gradient of thickness, and light diffusion (Figure 4). An agar bioplastic membrane was created during the prototype process using a mixture of water, vegetable glycerin/honey, agar powder, and seaweed liquid fertilizer. The mixture was heated for 3 minutes, then left to cool and dry on a surface for 10 days. The design evolved into a three-dimensional undulated membrane that created a space between the building's interior and the urban context, filtering light inward while sequestering blue carbon from the atmosphere.

Figure 3. Chitosan / rammed earth hybrid structure: Explorations in Midjourney, material experiments, physical prototyping and Ladybug simulation. Source: Naqib Nasser, 2024.

Figure 4. Seaweed / hydrogel hybrids Midjourney, material experiments and final model. Source: Sara Stabglieri, 2024.

Figure 5. Bamboo / bacterial cellulose / microalgae hybrid structure: Explorations in Midjourney and material experiments. Source: Nour Said, 2024.

3.4 Bamboo / bacterial cellulose hybrid structure

Another example of a soft skin explored the hybrid between bamboo and a bacterial cellulose/microalgae membrane. The text-to-image experiments were followed by a series of algae growth tests and bacterial cellulose cultivation. Algae were then mixed with bacterial cellulose and hybridized with various surfaces, such as jute fabric and rope, to create an interface between the biomaterial and the bamboo. (Figure 5)

3.5 Concrete hybrids with cork and loofah

Two concrete-based hybrids were explored. The first hybrid combined concrete and cork with the addition of moss in specific patterns. These patterns were investigated through Midjourney using a text-to-texture strategy with displacement mapping in Autodesk Maya (Figure 6). The second hybrid explored the interaction between concrete and loofah with varying percentages of soil in the mix (Figure 7). Midjourney provided patterns of loofah weaving and suggested appropriate voids and concrete paths to act as a structural network and binder for the loofah pieces.

All hybrid material distributions, starting from text-to-image inspirations, were incorporated into a three-dimensional skin/space and presented through a comprehensive set of drawings, plans, sections, and elevations. (Figure 9) The environmental performance of all hybrid materials was tested using Grasshopper and Ladybug simulations, as well as Autodesk CFD for wind simulations (Figure 8).

Figure 6. Cork / concrete / moss hybrid structure: Explorations in Midjourney. Text to Texture through displacement mapping. Source: Tiphaine Pottier, 2024.

Figure 7. Concrete and soil on loofah. Explorations in Midjourney and material experiments. Source: Elspeth Prowse, 2024.

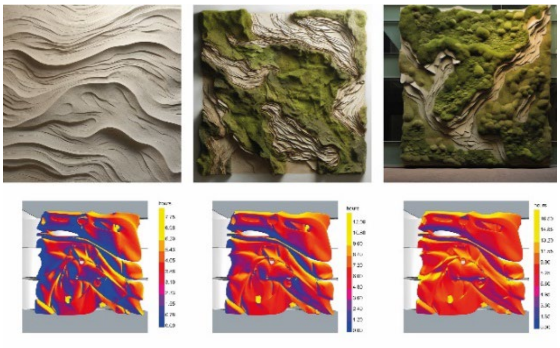

Figure 8. Concrete, cork and moss hybrid. Midjourney explorations and environmental simulations of the final model. Source: John Herrera, 2024.

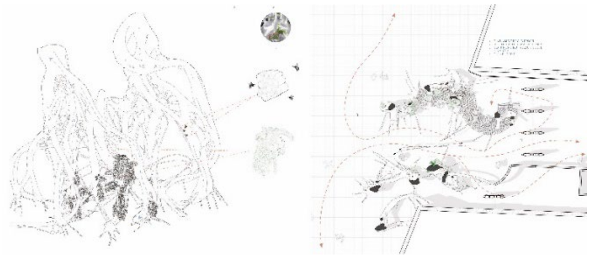

Figure 9. Urban Biodiversity Eco screen. Soft luminous biopolymer / solid recycled bioplastic. Source: Nicolas Guillot, 2023.

4 Discussion

The use of text-to-image ML models in design is still evolving, with tools advancing rapidly. While automatic conversion to detailed 3D environments remains limited, it is gaining traction. User communication and control methods are reshaping the current design decision-making process. In academia, students are required to demonstrate workflows related to design thinking and development that train the tool. This research explores material hybrids as protective envelopes that form a new skin for buildings, enabling adaptation to climate change while providing structure and space. Hybridizing biomaterials with traditional materials enhances scalability, and AI introduces new material interfaces and patterns that offer scalable solutions. AI in architectural education raises questions about combining traditional design media with new methods like machine learning in a non-linear approach. The process has been highly positive, both in terms of production and as a learning tool for deepening design understanding. ML outcomes served as references for analysis, redrawing, diagram creation, modelling, and fabrication.

Future research will focus on precise fabrication systems, exploring the lifecycle of material hybrids through components that can be replaced, recycled, refilled, assembled, and disassembled. The consistency of material mixtures could be adapted to varying climates and humidity levels, affecting both interfaces as well as primary and secondary materials.

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