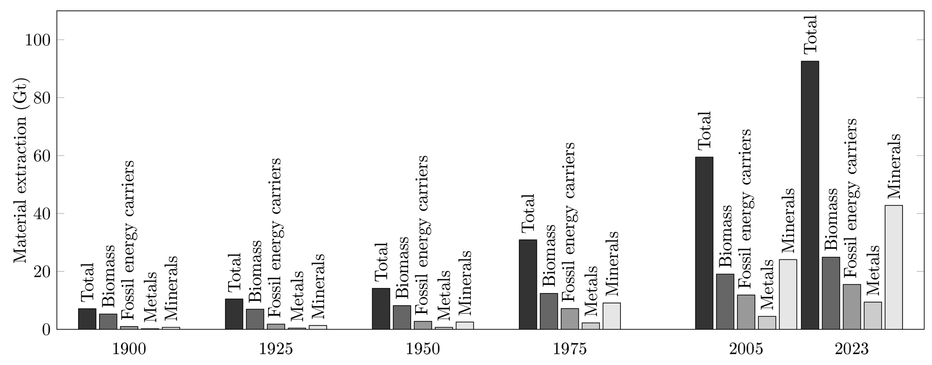
Understanding Growth for Engineered Living Materials

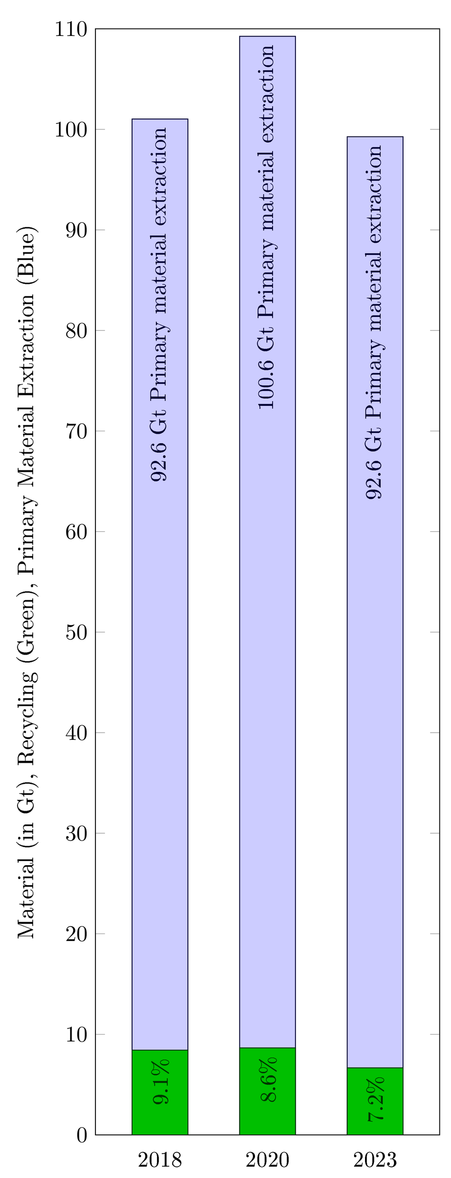
by simulating induced Gall Growth with an extended VirtualLeaf

Worldwide Resource Extraction



Worldwide primary resource extraction in Gt per year, the total bar is the sum of biomass, fossil energy carriers, metals and minerals [1].

Recycling - Unsuccessful



The current **recycling methodology**, involving collecting materials after the product's end of life for generic decomposition and subsequent reuse, **exhibits inefficacy**.

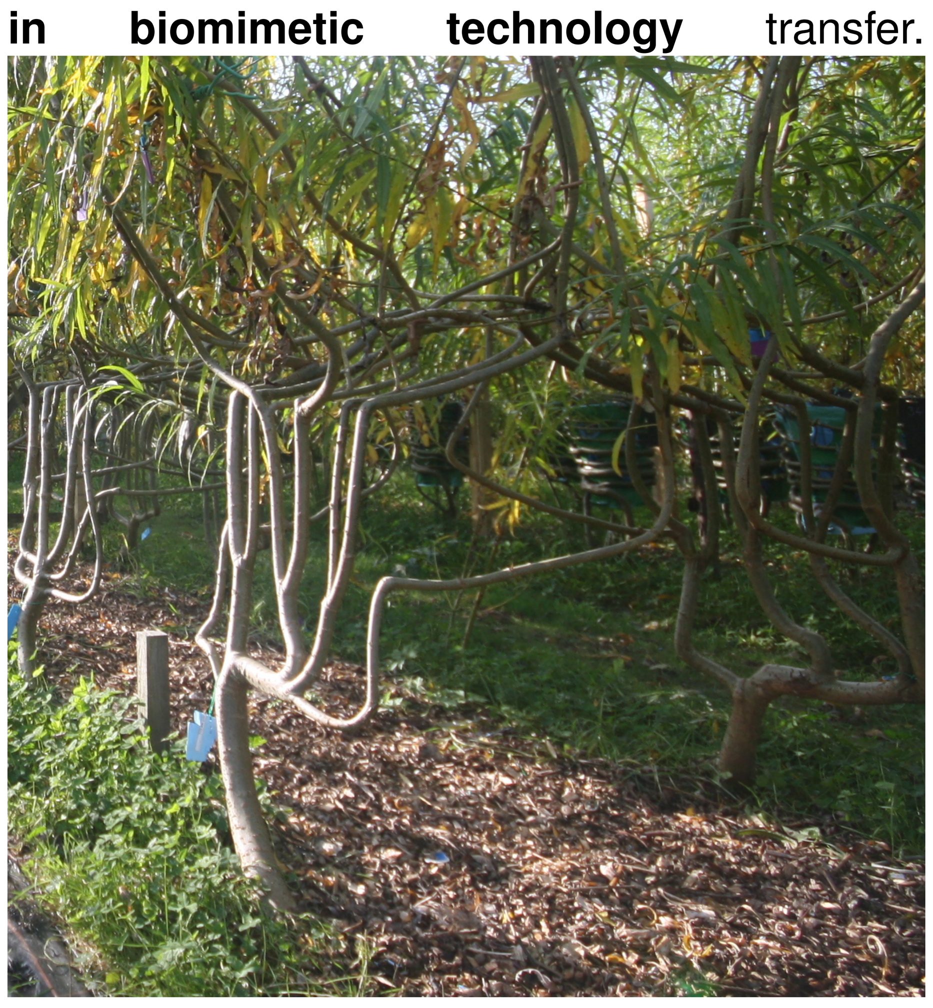
Despite substantial efforts invested in recycling since its resurgence around 1970, the proportion of recycled materials relative to primary extracted materials reached **only 7.2% by 2023**.

This discernible shortcoming underscores the imperative for a more transformative paradigm shift to alleviate resource consumption pressures effectively.

Engineered Living Materials (ELMs)

A new way of thinking about materials is necessary. **Living Nature has no recycling problems**, even though biological global net primary production is estimated to be 210 Gt of dry mass per year [2, 3]. For instance, chitin is an essential material that is used widely by insects for various functions [4] with no waste problem at all.

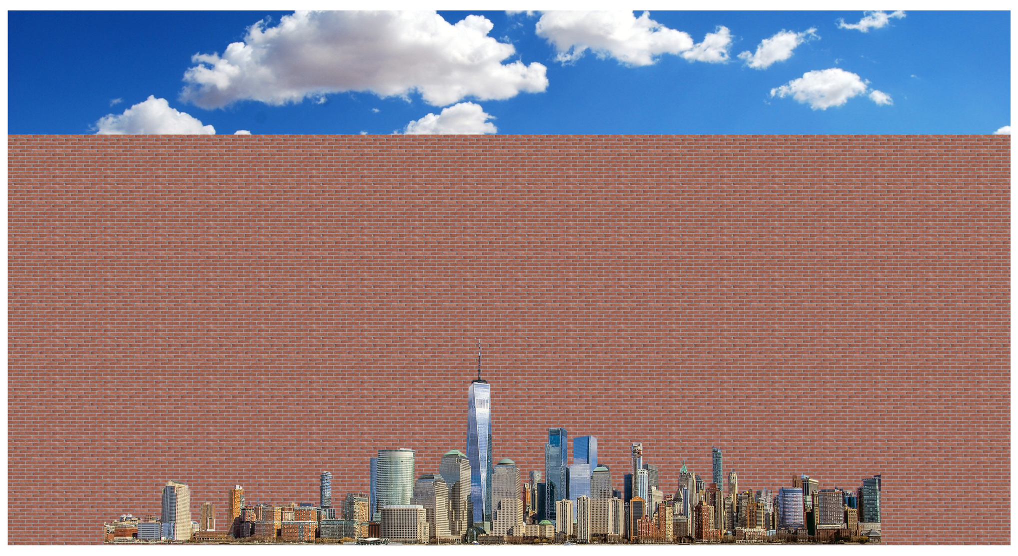
Biomimetics, has demonstrated the successful transfer of natural principles to technical applications.
However, in most cases, the **sustainability aspect is not addressed in biomimetic technology** transfer.



In contrast, the emerging field of Engineered Living Materials (ELMs) focuses on self-repairing, self-supporting growing materials and overall sustainability [5].

ELMs enclose a living component during the forming (engineering phase) or utilisation of the material and can additionally encompass non-biogenic materials.

Primary Material Extraction

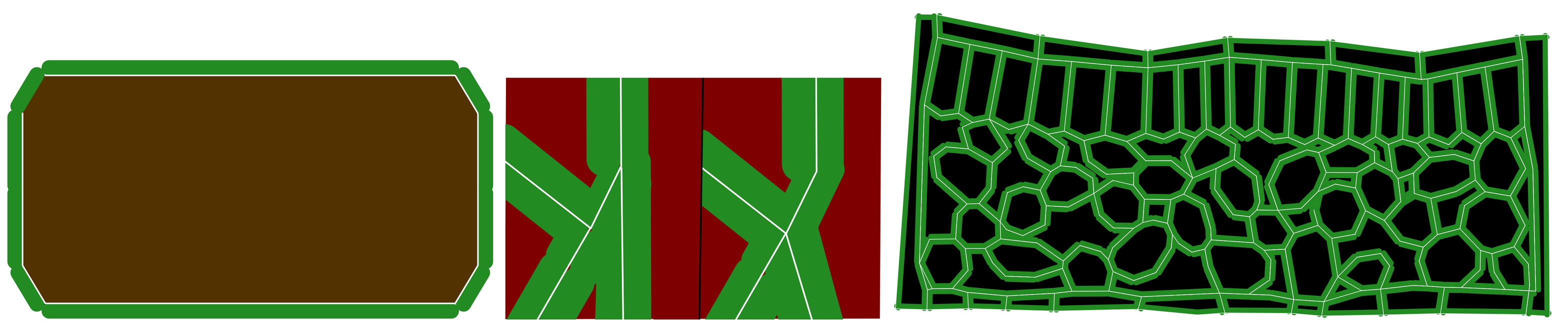


Primary material extraction remains unbounded, even exhibiting exponential growth (See Worldwide Resource Extraction) [6, 7]. Modern composite materials demand diverse resources **sourced globally**, contributing to an annual primary resource extraction equivalent to a concrete **wall stretching 1000 meters in height and 1 meter in width encircling the globe**. (The picture illustrates the wall running through the skyline of New York). Half of last year's monumental Wall, representing the global waste output, is dismantled and discarded annually. Forecasts indicate a persistent trend that the width of this symbolic Wall is projected to increase by 3 centimetres each year. This Wall underscores the **escalating challenges** of primary material demands and waste generation [1].

= 1 cm

Current State of Development

We are implementing multiple **new features** in VirtualLeaf in cooperation with Ruth Grosseholz (Maastricht University) and Roeland M.H. Merks (University Leiden). Publication of these new features is in preparation.

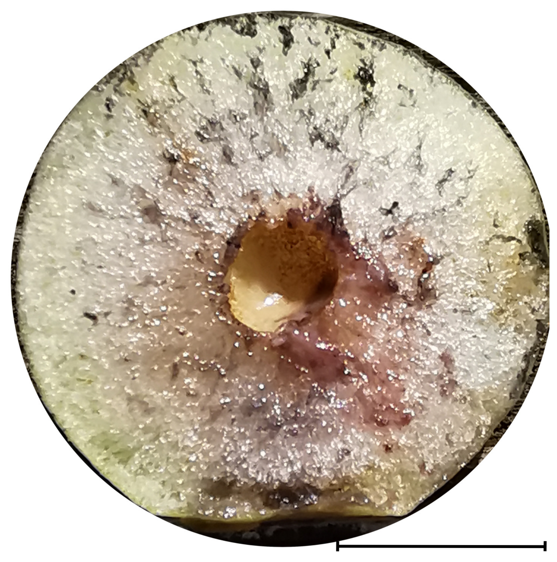


Cell form stability:
VirtualLeaf defines cell walls as the series of wall elements between two cells. We need longitudinal cells that hold their configuration for procambium cells and their differentiated xylem and phloem cells (plant cell types for generating vascular tissue).

Cell wall adherence:
In case two parallel cell walls grow close to each other, they will grow together and form a shared cell wall between the cells. If two cells press on a third cell from both sides, the third cell will not form a pointed end but will instead retract.

Simulation start design:
Vector graphic drawing importer enables complex initial states to analyse specific growth situations.

Plant Galls as Model for Understanding Growth

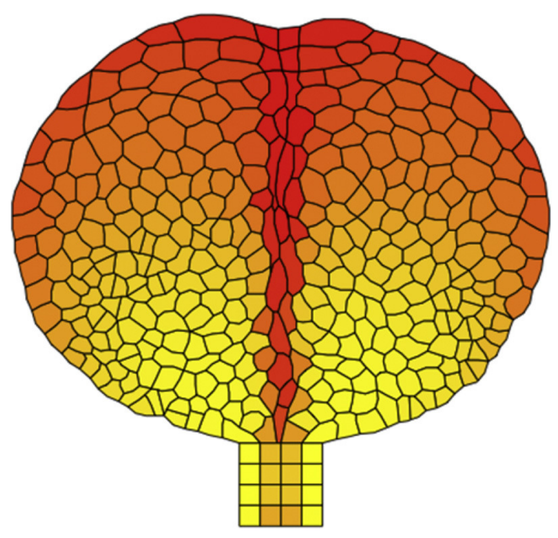


Plant Galls are frequently regarded merely as manifestations of plant cancer induced by parasites. However, a nuanced examination of these structures **unveils an intricacy and control** that amazes the engineer who is learning from Nature. Certain organisms, such as gall wasps, induce the growth of beading chambers in plants, providing a comfortable habitat for their offspring. Multiple instances of such structures are illustrated in the central image, with the scale bar denoting 1 cm.

The research question is:

"How can such a minimal change by the inducing organism in the plant metabolism cause the macroscopic construction of a breading camber."

VirtualLeaf



The development of plants over their lifespan is a highly complex, continuous process. Developing **growth simulation algorithms** furthers our understanding of the driving forces behind this process. The **VirtualLeaf** [8] software package is successfully used for **modeling plant and tissue growth**.

The latest developments in using growth algorithms to develop leaves can reproduce the maturing of a leaf [9]. The **VirtualLeaf** is based on a single-layer 2D model of cells and their interactions.

This study maps the 3D plant-gall structure to a **2D representation**. The plane through the galls symmetry axis is used to reduce the simulation to two dimensions. This **reduces the complexity** and still represents plant-gall growth in detail.

Outlook

After releasing the new features needed in VirtualLeaf, we want to simulate the growth of procambium between cambium cells.

Such a simulation would be a considerable step toward explaining the growth of veins in plant leaves.

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Exner Lectures 2024

Milestones for a future worth living
Vienna, Austria, May 2024

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