Press to Open:

Nature-Inspired Design for Easy-to-Open Metal Cans

Group 19

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INTRODUCTION

On average, a Dutch person opens seven packages a day. Over a lifetime, the average European opens approximately 140,000 packages (*Vooral Ouderen Hebben Problemen Met Het Openen Van Verpakkingen*, n.d.). A significant portion of these are food packages. Food packaging is primarily designed to preserve and protect its contents; far less emphasis is placed on usability. This imbalance can be particularly frustrating for the elderly or individuals with physical impairments, such as arthritis or rheumatism, who often struggle to open packaging.

Research conducted by ANBO and ReumaNederland found that 40% of respondents experience a daily struggle opening food packaging. Many, therefore, use other kitchen tools, such as scissors, for assistance in opening the packaging. This can lead to dangerous situations, with 55% of respondents indicating that they have been injured trying to open a package this way (reumanederland, 2019).

Given the ageing population across much of the Western world, the number of people living with physical limitations is steadily increasing (Sloot et al., 2016). This highlights the urgent need for research into food packaging solutions that are safer, more intuitive, and more user-friendly. In this project, the focus was placed specifically on designing an improved opening mechanism for metal cans.

The research was conducted using a top-down and biology-pull approach. This means that it started with a design problem. To solve this design problem, we examined how nature solves similar problems and drew inspiration from these solutions. The research questions that were formulated were:

- *How does nature achieve sealing, protecting, and controlling access?*

- *How can biological strategies inspire a safer, user-friendly opening mechanism for metal cans?*

Several organisms were studied for similar natural functions to answer these questions, including shellfish, heart valves, the Venus flytrap, explosive seed pods, and the touch-me-not plant. The seed dispersion mechanism of explosive seed pods (Impatiens glandulifera) was found to be the most interesting and promising source of inspiration for an opening mechanism for metal cans.

The explosive seed pods were further analysed, and a Biological Design Principle (BDP) was created. Based on this BDP, the underlying mechanisms of action were translated into an engineering context to create an Abstracted Design Principle (ADP). This ADP was then used to develop a functional opening mechanism for metal cans.

NATURE PRINCIPLES

To develop a more intuitive and energy-efficient opening mechanism for metal food packaging, five biological processes were explored. These processes were identified by conducting a biomimicry taxonomy analysis. The three main aspects of the research question, sealing, protection, and access control, were taken into account. They were found to be present in nature as part of two main functional groups: get, store, or distribute resources, and modify. The biological mechanisms of explosive seed pods, bivalve shellfish, heart valves, Venus flytraps, and touch-me-not plants were analysed. These organisms demonstrate various strategies, including tension-based triggering, passive pressure response, and stimulus-controlled movement.

Explosive Seed Pods

The triggering mechanism of explosive seed dispersal (ballochory) is observed in various plant species. This process allows seeds to be ejected away from the parent plant as part of its colonisation strategy. This analysis focuses on Impatiens glandulifera as an example to understand the biomechanical principles behind its explosive dispersal.

From a Biomimicry Taxonomy perspective, the primary function of the explosive seed dispersal is to move. This mechanism aims to transport the seeds away from the parent plant to facilitate dispersal. This is done by converting stored energy into kinetic energy to propel the seeds.

This triggering mechanism happens due to the controlled failure of specific weak points (dehiscence zones). This occurs when the mechanical stress, resulting from the storage of elastic energy, exceeds the material's fracture toughness at these specific weakened zones.

These energy storage mechanisms vary depending on the species. In the case of Impatiens, tension is created by the differential drying and shrinkage of its tissues (Poppinga et al., 2012). However, in Cardamine hirsuta, tension is generated through turgor pressure, anisotropic cell growth and specific cell wall structures, even while the fruit is hydrated (Hofhuis et al., 2016). In the specific case of Impatiens glandulifera, known for its high energy efficiency, it exhibits specific structural adaptations that optimise its energy release. Its seed pod valves are tapered, which allows the dehiscence zones to partially crack without causing a premature explosion (Deegan, 2012).

This designed failure happens at the dehiscence zone due to its specific cellular structure. It generally consists of a layer of lignified (strengthened) cells located next to a layer of non-lignified (weakened) ones, creating a line with low structural integrity designed for failure.

Once the fracture starts at the weak point, it quickly propagates along the dehiscence zone. This rapid structural failure releases the stored elastic energy almost instantaneously. In the case of the Impatiens glandulifera, the energy cost of breaking the pod is much lower due to the pre-cracked seams (Deegan, 2012).

Moreover, this explosive release can also be triggered by external contacts. Despite the internal tension growing with time, it is usually small mechanical disturbances that trigger the explosion. These can include environmental factors such as raindrops or wind, but also interactions with animals, like caterpillars feeding on the plant. This high sensitivity to contact highlights how a minimal trigger can translate into a larger mechanical response.

This exploding mechanism exemplifies several of Life's Principles, with resource efficiency (material & energy) being the most evident one. Within this category, the principle Fit Form to Function is key. As explained, the fruit's form, particularly its dehiscence zone, is adapted to function by storing energy and releasing it quickly after fracture. This involves strategic material placement to generate tension and create precise failure points.

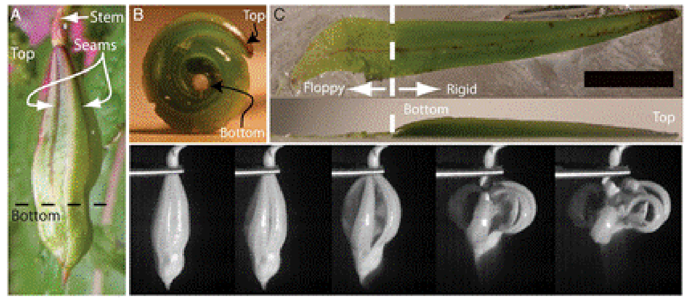


Figure 1. *Impatiens glandulifera (Deegan, 2012)*

Shellfish

There is a variety of animals with a hinged, harder outer shell, such as clams, mussels, oysters and scallops. They all belong to the same animal class called bivalve molluscs. The shell opening and closing in this animal class is largely the same, with differences only in the number and size of the muscles and optimisations of the fibres.

From a Biomimicry Taxonomy perspective, the primary function of the shell movement of bivalve molluscs is to modify their position in the water. Escaping predators or improving environmental conditions is achieved by repeatedly opening and closing the shell. This allows the shellfish to “swim” to different locations.

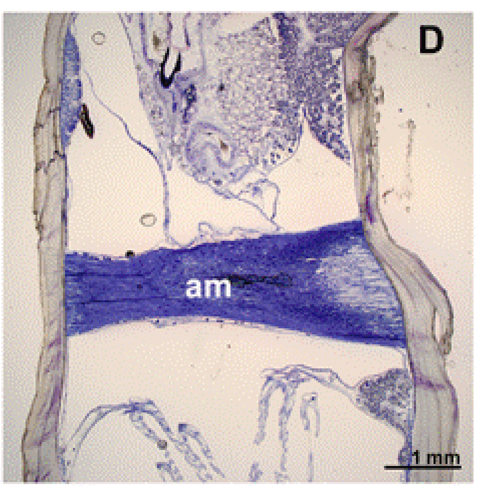


Figure 2. *Adductor muscles in Ostrea stentina (Castro-Claros et al., 2020)*

Bivalve molluscs consist of two hard shell halves with a soft body inside. The two shell hard halves are held together by a strong, flexible tissue (ligament) called abductin. Abductin consists primarily of amino acids but is composed in a way that it has spring-like properties. This ligament is therefore also called a protein rubber, since it largely functions the same as synthetic rubber, but is made from organic material (Vogel, 2003).

Adductor Muscles are also connected to both shell halves (see figure 2). Adductor muscles are a type of muscle with striated fibres that pull parts of an organism’s body to the midline by contraction (Castro-Claros et al., 2020). In bivalve molluscs, the

Adductor muscles use energy from the organism to contract to pull the shell halves together and close the opening.

This contraction of the adductor muscles compresses the abducting ligament (Denny & Miller, 2006). The abduction ligament has spring-like properties and stores energy when compressed by the contraction of the adductor muscles. When the adductor muscles relax, the abduction ligament recoils to its original form, thereby helping the shell spring open (Tremblay et al., 2015).

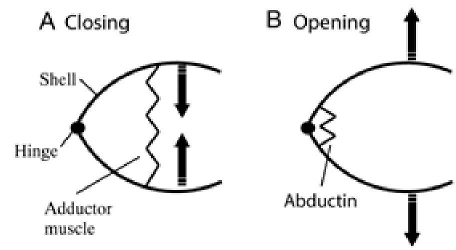


Figure 3. *Opening and closing mechanism of Adamussium colbecki (Denny & Miller, 2006)*

The main relevant life principle about functionality and mechanism is to be resource efficient by leveraging physics and using low-energy processes. The elastic recoil nature of the abduction ligament allows for opening the shell without the need for muscles, saving energy in the process.

Heart Valve

Heart valves are essential structures in the human cardiovascular system that ensure blood flows in only one direction through the heart. This function aligns with the Biomimicry Taxonomy category of “Control Fluid Flow – Prevent Backflow.” The four main valves in the heart are the tricuspid, mitral, pulmonary, and aortic valves. They open and close in response to pressure changes in the heart’s chambers and vessels (Cleveland Clinic, 2017).

Valves function passively and do not require muscle contractions to open or close. Instead, they respond to pressure gradients. When pressure behind the valve is higher, it opens to allow blood through. When pressure in front becomes greater, the valve shuts tightly to prevent blood from leaking backwards (Yoganathan et al., 2004). This mechanism is automatic and highly efficient, happening with every heartbeat.

The atrioventricular valves (tricuspid and mitral) are supported by chordae tendineae—thin, strong cords that attach to ventricular papillary muscles. These prevent the valve leaflets from flipping backwards during ventricular contraction. The semilunar valves (pulmonary and aortic) have three pocket-like cusps that fill with blood and close the valve when backflow occurs (TeachMeAnatomy, 2016).

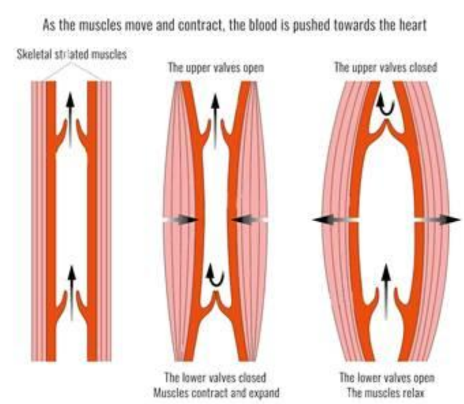


Figure 4. *Venous Valve Function with Muscle Movement (Alamy Limited, 2020)*

Figure 4 shows how venous valves work in coordination with surrounding skeletal muscles to maintain one-way blood flow toward the heart. In the resting state (left), both valves are closed to prevent backflow. When the muscles contract (middle), pressure increases, the lower valve closes, and the upper valve opens, pushing blood upward. When the muscles relax (right), pressure drops, the upper valve closes, and the lower valve opens to let more blood enter from below. This passive, pressure-controlled system reflects the same operating principles used by heart valves.

To conclude, the heart valve system aligns with several of Life's Principles:

- Leverage cyclic processes: Valves open and close rhythmically with each heartbeat.
- Use feedback loops: Valve movement depends on real-time pressure differences.
- Be resource efficient: Valves require no active energy to function; their motion is entirely pressure-driven.

Venus Fly Trap

The Venus Fly Trap, also known as the Dionaea Muscipula, is a carnivorous plant that actively catches prey (Dubinovand & Lyubimtseva, 2022). It does this with the help of a leaf trap; the mechanism of this leaf trap ensures rapid closure, resulting in the capture of prey.

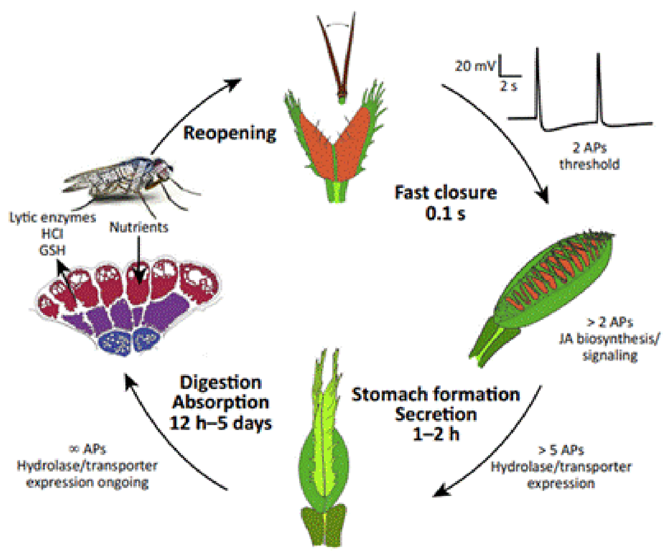


Figure 5. *The Hunting Cycle of Dionaea muscipula (Hedrich & Neher, 2018)*

From a Biomimicry Taxonomy perspective, the main functionalities of the Venus flytrap are sensing, responding, and capturing/closing. The mechanism causes stimuli to be sensed, it reacts to specific stimuli with movements and traps the prey.

Figure 5 shows the capture and digestion process of the Venus flytrap. This process consists of several stages, which ensure that the organism can achieve its functions. When the Venus Fly Trap is starving, it creates intensely red-coloured inner traps and it gives off more than 60 volatile organic compounds of fruit and flower scents, which will attract insects. The insides of leaf traps possess highly sensitive mechanoreceptors in the form of trigger hairs. When an insect touches these trigger hairs in the trap, electrical signals are generated, and an action potential (AP) is activated. The plant has a kind of “short-term memory” and “remembers” the number of APs. When there is one AP, this is remembered, but nothing else happens yet. Only if a second AP is triggered within about 30 seconds, a rapid shutdown (about 100 ms) follows (Forterre et al., 2005). If the time between the first and second AP is more than 30 seconds, the trap does not close (Hedrich & Neher, 2018).

If more than two APs occur, production of the signalling substance jasmonic acid (JA) is initiated. At five or more APs, the JA clock and genes for digestive enzymes and nutrient transporters are activated. The number of APs thus determines whether the plant closes or not, and whether the plant only closes or also continues digestion. With five or more APs, the leaf trap is also sealed airtight, so the leaves form a kind of "stomach" in which the previously mentioned digestive enzymes and nutrient transporters can be produced (Hedrich & Neher, 2018).

Digestion and absorption then take place. During this phase, action potentials continue to take place, and nutrient uptake is also regulated by the number of APs. Enzymes, such as hydrolases, are secreted to break down the prey ash and take up nutrients (Hedrich & Neher, 2018). Once digestion is complete, the trap opens again. The indigestible remains of the prey are left behind.

Several Life's Principles apply to the Venus Fly Trap. First, the Life's Principle 'Adapt to changing conditions' applies, as the plant lives in nitrogen-poor soils. To survive in these conditions, the plant has adapted by becoming carnivorous. However, the principles "Be resource efficient" and "Use feedback loops" also apply to the plant. Since the plant closes only on repeated touches. APs regulate their actions, and digestive enzymes are produced only when there is actual prey worth this energy. These things prevent unnecessary energy loss.

Touch Me Not Plant

Mimosa Pudica Plant, also known as the 'Touch Me Not' plant, is known for its leaves that can close quickly and the stem that can sag after the plant is touched (Stolarz & Trębacz, 2021).

From a biomimicry taxonomy perspective, the key function of the Mimosa Pudica is to protect. The mechanism of the plant does this by detecting touch and retracting its leaves.

When the plant is touched, it closes its leaves. The plant does this to protect itself (defence mechanism), to scare away insects, or to give the impression that it is dead or dying. Which makes it, therefore, not as appealing and nutritious as other plants for animals that could eat the plant. The leaves are closed with the help of the pulvini (Volkov et al., 2009). Pulvini are present at the base of each leaflet, stem, and branch (Hagihara & Toyota, 2020). They consist of cells filled with water, which applies pressure against the walls of the cells, also known as turgor pressure.

When the plant is touched, electric signals (like action potentials (APs)) are passed through the pulvini of each leaf, which causes the plant to release ions, such as potassium (K^+) and chloride (Cl^-). These ions rapidly flow out of the cells, making the environment outside the cells saltier. Causing the water inside the cells to leave and go to the adjacent cells by a process of osmosis. (Volkov et al., 2009) This causes the cells in the pulvini to lose water. When water is lost, there is no more turgor pressure. This results in the cells collapsing and a change of shape, resulting in the closing of the leaflets (Hagihara & Toyota, 2020; Volkov et al., 2009). Figure 6 shows how the leaflets in a mimosa plant close due to the changes in turgor pressure in the pulvini. After the movement, the plant has to recover. The plant does this by actively pumping the cells' ions and water back in, restoring their original pressure and shape.

The two life principles that are most relevant to the functionality and mechanism of the Mimosa pudica are ‘Adapt to changing conditions’ and ‘Be Resource Efficient’. To survive, the plant has had to adapt to an environment with high predation pressure; it has done this by quickly closing its leaves when touched. Because this movement happens through the use of turgor pressure, the plant uses its energy efficiently. And the plant can make smart movements with minimal effort.

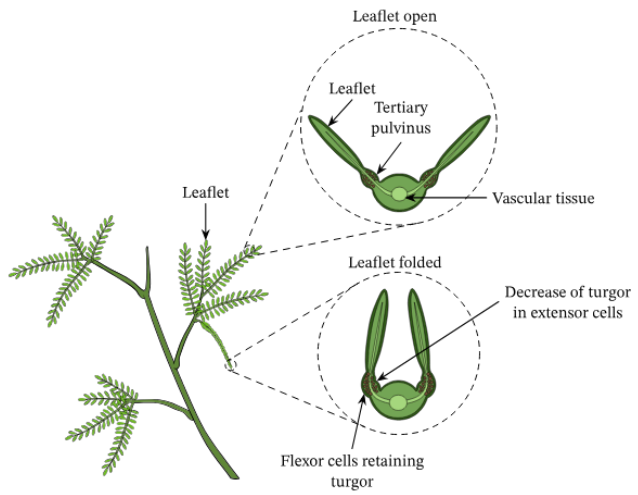


Figure 6. *Closing of the leaflets in a mimosa plant due to the change in turgor pressure in the pulvini (Lesson Explainer: Sensitivity in Mimosa Plants, Nagwa, n.d.)*

Results

The conducted literature review aimed to find a suitable organism to draw inspiration from for designing a more user-friendly opening mechanism for food packaging. For this purpose, it was looked at how nature achieves sealing, protecting, and controlling access. The Explosive Seed Pods, Shellfish, Heart Value, Venus Fly Trap, and the Touch Me Not plant were looked at. It was examined in what way they move, build up pressure, and respond to stimuli. And how they use this to seal, protect, and control access.

Based on the functions and mechanisms of these organisms, the explosive seed pods offer the most potential as an inspiration to design a more user-friendly opening mechanism for food packaging. The combination of the passive tension build-up and the automatic and powerful movement that follows makes this principle the most suitable for further investigation for a nature-inspired opening mechanism for food packaging. That’s why the explosive seed pods are analysed further and a Biology Design Principle (BDP) is elaborated for this organism.

BIOLOGICAL DESIGN PRINCIPLE

The explosive seed dispersal mechanism in Impatiens glandulifera serves as the biological model for this project's design challenge. In nature, this mechanism enables efficient seed dispersal by transforming stored elastic energy into rapid motion triggered by minimal external input.

In Impatiens glandulifera, the seed pod walls consist of two layers: a contracting outer layer (exocarp) and a stiff, inner lignified layer (endocarp b). As the fruit matures, the exocarp actively shrinks due to dehydration and turgor-driven contraction, while the stiff inner layer resists this movement. This opposition results in elastic energy being stored between the layers, creating a pre-stressed, bowed geometry across the pod valves (Hofhuis et al., 2016).

Strategically weakened seams, known as dehiscence zones, form as the pod ripens. These zones consist of adjacent lignified and non-lignified cells, giving them low structural integrity and making them prone to failure (Deegan, 2012). When a minor mechanical stimulus such as wind, touch, or contact with an animal is applied, these seams rupture. This localised failure releases the built-up tension and triggers a snap-through instability, causing the valves to rapidly flatten and coil backwards, launching the seeds explosively (Hofhuis et al., 2016; Deegan, 2012).

This system also employs a pre-cracking strategy, meaning only a small portion of the seam needs to fail to initiate the release. This cascading failure reduces the energy threshold needed for activation, making the mechanism both energy-efficient and highly sensitive. As Deegan (2012) explains, the pod's tapered shape supports this process by delaying premature rupture while maximising kinetic energy upon release.

From a Biomimicry Taxonomy perspective (Function and Strategy - Biomimicry Toolbox, 2023), the mechanism falls under the primary function “Move,” and more specifically “Disperse” or “Release” via triggered structural failure. It illustrates how biological systems can passively store tension and release it efficiently through geometry, material contrasts, and structural responsiveness.

This system is visually summarised in Figure 7, which outlines both external and internal views of the explosive dispersal process. It illustrates three key stages: (1) stored tension in the bilayer structure, (2) rupture triggered by minimal input at weak zones, and (3) rapid coiling and seed ejection. The cross-sectional diagrams further highlight how differential contraction between layers builds internal stress until structural failure is triggered. This overview supports a clearer understanding of the Biological Design Principle (BDP).

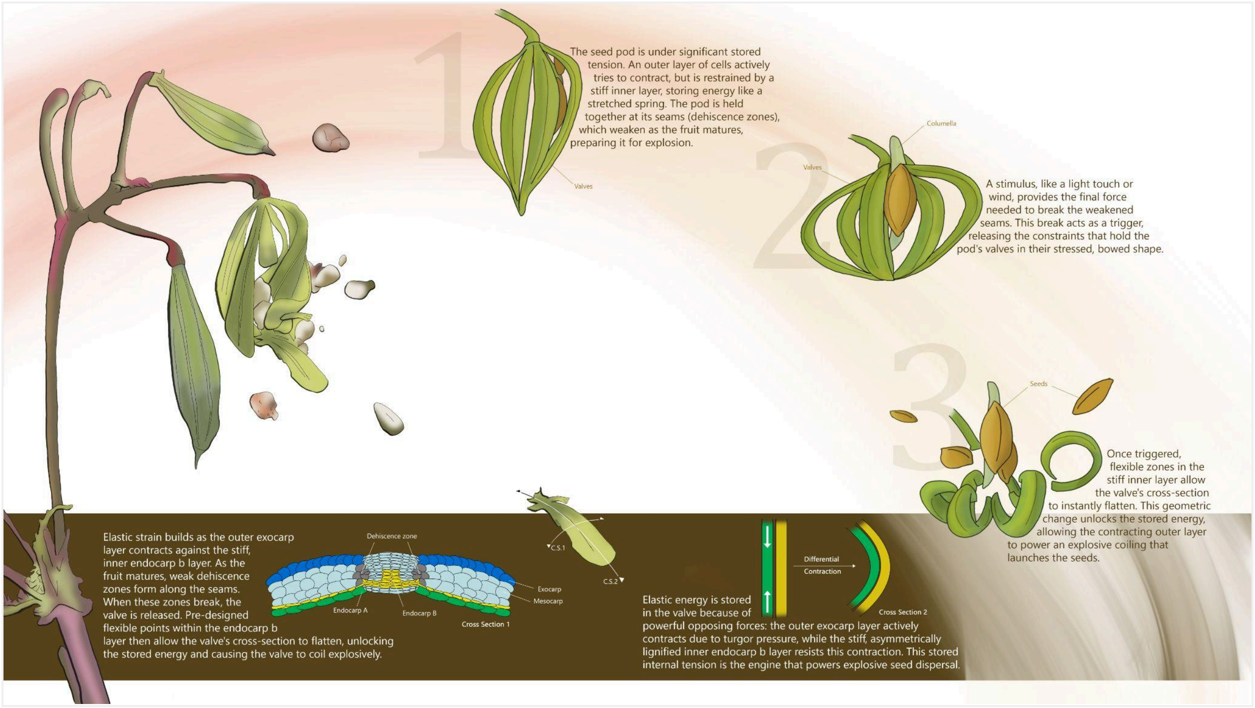


Figure 7. *Biological Design Principle (BDP) of explosive seed dispersal. The sequence shows (top) tension buildup, triggering, and explosive movement, and (bottom) the bilayer cross-section with stored elastic strain and responsive flex zones.*

This biological mechanism exemplifies several of Life's Principles (DesignLens: Life's Principles - Biomimicry 3.8, 2024). Most notably, it uses low-energy processes by relying on naturally occurring tension from dehydration and cell wall contraction, rather than active metabolic input. It also fits form to function, as the pod's bilayered, pre-stressed geometry and tapered seams are evolved to store and release energy efficiently through controlled failure. The system is locally attuned and responsive, triggering only when minimal environmental cues like touch or wind are present, demonstrating the use of feedback loops and readily available energy. Additionally, the structure develops progressively during the fruit's growth, aligning with the principle of integrating development with growth through self-organisation and bottom-up construction.

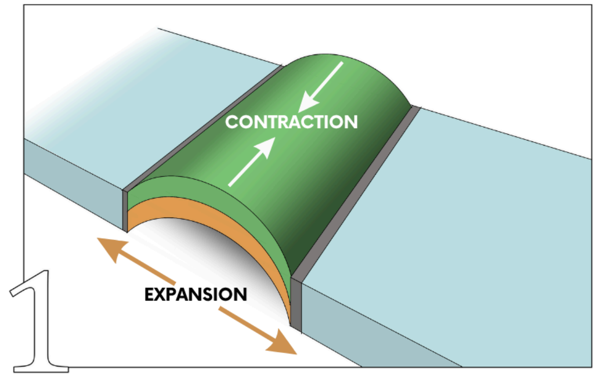
This Biological Design Principle (BDP) forms the foundation for the Abstracted Design Principle (ADP) developed in the next section, where the natural mechanism is translated into an engineering design strategy.

ABSTRACTED DESIGN PRINCIPLE

This chapter explains how the biological design principle (BDP) is translated into engineering terms, creating the Abstracted Design Principle (ADP).

The following images illustrate this 3-step process, translating the biological functions of explosive seed pods into engineering terms that guided our final design.

Green is the contracting layer, orange is the resistant layer, grey parts are the weak zones, and blue is the side walls restricting movement.



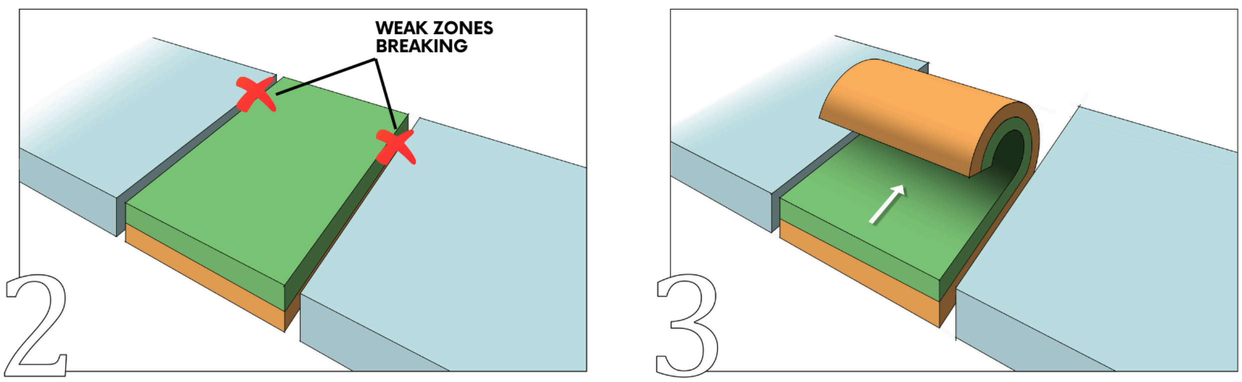


Figure 8. *Abstracted Design Principle (ADP)*

Step 1: Energy storage
Following the seed pod's structure of layers with opposing tendencies, our engineered "valve" stores elastic energy. An active outer layer (green) is designed to contract, creating a coiling force. This action is restricted by a stiffer inner layer (orange) which, combined with the side constraints, holds the valve in a curved shape. This bowed layer acts as a geometric lock that prevents coiling, loading the system until the weak zones fail and the chain reaction starts.

Step 2: Trigger & flattening
An external stimulus, like a user's touch, causes the weak zones to fail. This failure removes the structural constraints that were holding the valve in a tensioned state. Once free, the valve starts its pre-programmed movements by first flattening its cross-section.

Step 3: Coiling
Finally, this flattening eliminates the valve's geometric restriction. Therefore, the stored elastic energy is released, leading to the valve coiling backwards and completing the opening.

REDESIGNED METAL CANS

For the incorporation of the ADP into a product, we decided to focus on the redesign of metallic cans. This packaging type is seen as one of the most difficult to open food packaging types by research from Rheumanederland, and there is a clear way to apply the design principle to improve the opening mechanism of this package to be safer, faster, and more accessible for all users.

The final product is a two-piece metallic can, consisting of a single-piece aluminium body and a separate lid assembly. The lid incorporates the abstracted design principle within its opening mechanism.

Figure 9. *Render of the redesign of metallic cans with an improved opening mechanism*

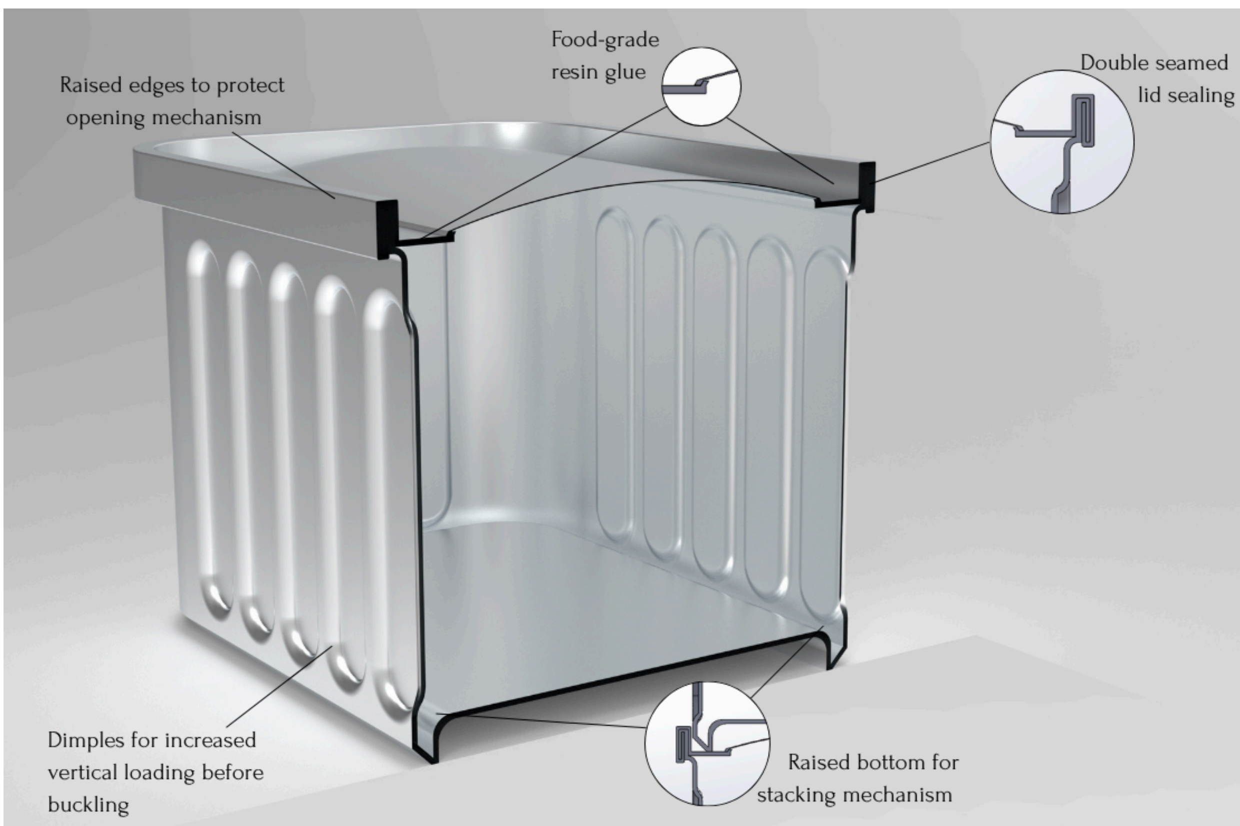


Figure 10. *Overview of design aspects of the redesigned metallic can*

Can Body

The can body features a rectangular profile with rounded corners and side dimples for improved ergonomics and grip. The standard design holds approximately 350 ml, with external dimensions of 70 mm (width) × 125 mm (height) × 65 mm (depth). These dimensions are flexible and can be adjusted without affecting the underlying design principle.

Structural Design:

- A raised bottom allows for vertical stacking while preventing interference with the lid's opening mechanism.
- Raised top edges extend above the lid plane to protect the opening mechanism from impact or damage.

Manufacturing Process:

- Produced using a conventional draw and redraw method from a single sheet of aluminium.
- Dimples are formed post-drawing to enhance the can's vertical load capacity.
- The process is consistent with current aluminium can manufacturing, requiring no significant alterations to existing production infrastructure.

Lid Assembly

The lid consists of two interlocking components that together form the opening mechanism, incorporating the abstracted design principle.

Outer Lid

- Constructed from aluminium and designed to match the shape of the can body.
- Features a large central opening, rounded on one side, to accommodate the inner lid.
- The outer lid can be attached to the can body using the existing sealing technique (double-seamed), eliminating the need for new attachment methods.

Figure 11. *Outer lid design*

Inner Lid

- Made from a slightly bowed steel insert that fits precisely on top of the opening of the outer lid.
- This steel piece stores elastic energy in its bowed shape, wanting to release this energy by flattening and coiling itself.

Figure 12. *Outer and inner lid together*

Assembly

- The two components of the lid are bonded together on three sides using food-grade epoxy resin, while the fourth side is permanently fixed (welded) to keep the piece attached to the can when opening.

Figure 13. *The lid after the opening mechanism is activated*

Opening mechanism

Primed state

The can is sealed with a 2-piece lid, consisting of a steel inner lid that is glued in its bowed shape to the outer lid. This steel stores elastic energy in its sealed, bowed shape because it naturally wants to expand (flatten) and contract (coil), but cannot because it is glued in place.

Trigger

The user applies pressure with their finger, starting at one side of the bowed inner lid and moving across its length.

Seal failure

This force applied by the user on the inner lid should be enough to break the “weak zone” of the epoxy resin between the inner and outer lid.

Opening action

As the adhesive seal breaks, the inner lid is released from its constraints. It instantly releases its stored energy by first flattening its cross-section and then rapidly coiling backwards, tearing away from the outer lid, revealing the opening in the inner lid, and access to the content of the can.

CONCLUSION

A safer and more accessible method for opening metal food cans has been designed. The design specifically addresses challenges faced by elderly individuals and those with physical disabilities when opening conventional packaging.

A metal can was created, where the inner lid, made of a slightly bowed steel layer, is bonded to the outer lid on three sides with food-safe epoxy, and mechanically fixed on the fourth. When the user applies pressure to the bowed area, the weak bond breaks, causing the inner lid to release its elastic energy and snap flat and coil, safely exposing the can's contents.

This method significantly reduces the effort and physical ability required to open metal cans, whilst at the same time improving safety since there is no torn metal with this opening mechanism and thus no sharp metal edges to cut yourself on.

This will vastly improve the independence of the elderly and people with physical disabilities, allowing them to open cans safely and without help, allowing for more independence in preparing food and more food options available in supermarkets for them.

The use of biology principles to improve packaging opening mechanisms makes a lot of sense when looking at life's principles. Energy is a scarce resource, and thus being energy efficient is of great importance. Using these nature principles to minimise the energy needed to open packages will benefit many people in our society and improve the usability of packaging.

Further development

To further develop this product, further research and development in two main aspects are needed.

First, the attachment of the inner lid to the outer lid needs to be optimised and perfected. This needs to be strong enough not to have the can open at the slightest bump to the opening mechanism, but it should also not require too much force, since that would remove any benefit from the solution. Thus, further testing on what an acceptable opening force is needs to be done, ideally in collaboration with Rheumanederland. Then, based on that information, the ideal combination of attachment points and glue between the inner and outer lid needs to be determined. To achieve the needed breaking of the "weak zones" at the specified pressure force.

Second, the recyclability of the cans needs to be further assessed. Currently, cans are made of a single metal type, making recyclability relatively easy. However, the properties needed for the opening mechanism are, as far as we are aware, only present in steel, making this design consist of two types of metal: steel and aluminium. Further research and development needs to be done to assess whether this is a problem for recyclability, and if so, how this can be solved to make the cans as recyclable as current metal cans are.

In conclusion, this design demonstrates how biological principles can inform innovative engineering solutions, especially for inclusive and user-centred product development.

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