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What is variety engineering and why do we need it?

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Abstract

Management in systemic terms means to cope with complexity. Ross Ashby's law of requisite variety shows the way—maintaining the varieties of interacting systems in balance. To denote that process, we use the cybernetic concept of 'variety engineering', which we also formalize. It refers to processes of mutual complexity amplification and attenuation by interacting agents. The purpose of this contribution is to elicit ways of coping with complexity by means of variety engineering. The abstract concepts are illustrated by examples from ecological, social and economic contexts.

KEYWORDS

management of complexity, requisite variety, sustainability, systemic management, variety engineering

1 | INTRODUCTION

This is a conceptual essay on an abstract topic: variety engineering. We will illustrate this methodology using the topic of sustainability.[1] This is to show the path from theory to practical application.

Enabling and fostering sustainable ways of coexistence with the environment is a burning issue of managing complexity.

Sustainability has been defined in ecological and systemic terms by at least two authors: First is by Gro Harlem Brundtland, a prime minister of Norway and chairwoman of the United Nation's Commission on Environment and Development (WCED) that published the report 'Our Common Future': 'Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (Brundtland, 1987). Second is by Michael Ben-Eli, the founder of the Sustainability Lab in New York who defines sustainability as 'a dynamic equilibrium in the processes of interaction between a population and the carrying capacity of its environment such, that the population develops to express its full potential without producing irreversible adverse effects on the carrying capacity of the environment upon which it depends' (Ben-Eli, 2012).

Meanwhile, the ecological focus has been complemented by the goal of 'socially inclusive and environmentally sustainable economic growth' (Sachs, 2015, p. 5). Figure 1 shows that these three dimensions of sustainability are linked in principle.

The purpose of this contribution is to elicit ways of coping with complexity by means of variety engineering. Our research questions are:

1. What is variety engineering?
2. Why do we need it?
3. How does it work?

[1]This link to sustainability is also due to the Congress of Systems in Brazil—'17° Congresso Brasileiro de Sistemas'—where the first author gave a lecture on 9 November 2022, which was the basis for this article. The motto of that conference was 'Cybernetics of Sustainability: Design, Transformation and Learning' (translated by M.S.).

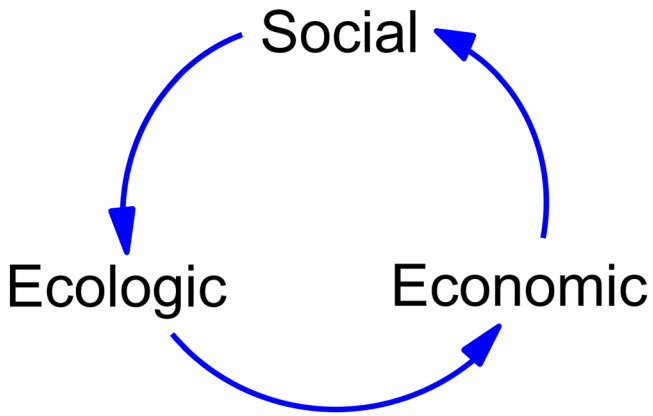

FIGURE 1 Three dimensions of sustainability. [Colour figure can be viewed at wileyonlinelibrary.com]

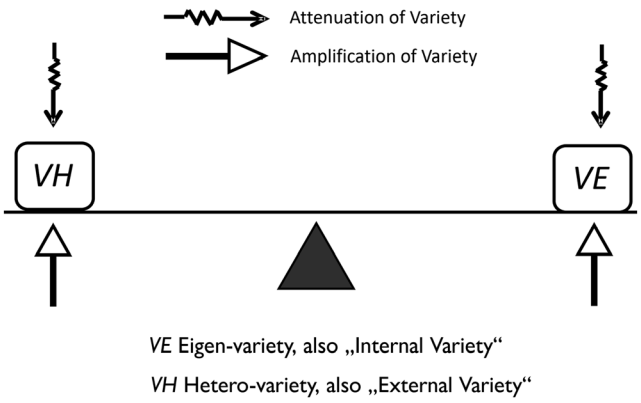

FIGURE 2 Levers of variety engineering—amplification and attenuation.

Cases in point will be used to demonstrate how complexity can be managed in order to foster sustainability in the three dimensions outlined.

In cybernetic terms, dealing with complexity hinges on Ross Ashby's law of requisite variety: 'Only variety can absorb variety'.[2] In other words, to maintain a system under control, the control system needs a variety that is (at least) equivalent to the variety of the system controlled. *Variety* is a technical term for *complexity*, which stands for the property of a system to adopt many different states or behaviours. Variety then denotes the (potential or actual) set of states or modes of behaviour of a system. A synonym is *repertoire of behaviours*.

Ashby noticed that the variety of a system is not an intrinsic property of that system. 'The observer and his powers of discrimination may have to be specified if the variety is to be well defined' (Ashby, 1956, p. 125). In the context of the management of complexity, different distinctions can apprehend variety, for example:

1. as a set of components or elements of the system or its environment: V_c
2. as a set of states of the system or its environment: V_s
3. as a set of modes of behaviour of its environment: V_b
4. as a set of perturbations coming from the environment: V_p
5. as a set of actions or responses of the systems: V_r

In an earlier treatise, variety engineering is conceived as 'managing the complexity of a situation', in terms of the mutual adjustment of $_{Vp}$ and V_r (Espejo & Reyes, 2011, p. 50f.). We revert to the more abstract concepts of *VE* and *VH*—eigen-variety and hetero-variety. Any one of the distinctions listed above can be used, if a given situation of variety engineering is analysed. Two examples:

1. *VEc/VHc*, that is, eigen- and hetero-variety, each of a set components.
2. *VEb/V*Hb, that is, eigen- and hetero-variety, each of a set of (modes of) behaviours.

We are going to use these two variants in the following cases. A characteristic of these sets is that their properties can be represented by quantitative data (Espejo & Reyes, 2011).

Any agent—individual or collective—confronts complexities that are superior to what he or she can attend fully with their variety, that is, their capacity of absorbing complexity. Variety engineering is the general strategy to offset this deficit.

'Variety engineering' is a term coined by Stafford Beer (1979, p. 39). It stands for the combinations of amplification and attenuation used to bring a system of interactions into balance. Amplification and attenuation are the actions or strategies by which the hetero- or eigen-varieties of a set or agent are changed,[3] according to a quantitative measurement scale.

The primary modes of variety engineering consist in attenuating hetero-variety (also: external variety) and enhancing eigen-variety (also: internal variety) (see Figure 2). Let us take, as two interacting agents, a complex market and a company. In this example, the company has two options:

1. To attenuate the complexity/variety of the market, for example, by modelling, structuring or segmenting it,

[2]Originally the wording of the law was 'Only variety can destroy variety' (Ashby, 1956). Later, Stafford Beer (1985) introduced 'absorb', instead of 'destroy' (p. 26).

[3]Such changes are triggered by factors that we also call *levers*.

inventing new ways of clustering market objects, targeting its own activity to parts of that market only (e.g. specific segments of the market) or reframing the system-in-focus.
2. To amplify its own variety/complexity, for example, by enhancing its market intelligence, adopting better information systems, increasing the sales force, strengthening its capabilities, etc. Also here, reframing is the most powerful device of variety engineering.

Hence, the ultimate way of both attenuating hetero-variety and amplifying eigen-variety is reframing, that is, redefining the context or the system.[4] These changes rely on inventing alternative realities and therewith creating new possibilities: In this way, new opportunities are created (amplification), and the strategy becomes more focused, that is, the context is made less complicated (attenuation).

Attenuation and amplification go hand in hand. A case in point is the question of the company's identity. The company should ask herself, if the markets it is engaged in have a fit with its identity, or if the target markets need to be redefined or refocused (attenuation of complexity). At the same time, it needs permanently to ask the question, if it is viable in the long run, respectively, if its traits, structures and capabilities, etc., need to be reframed or improved (amplification of variety).

The two minor levers of variety engineering are less triggers of action than of perception and understanding:

1. Amplification of hetero-variety: Let us assume that in our example, it is not possible to change the market (we know that in other cases this might be different). It is important to understand which are the factors that generate the complexity of the market, for example, individualization, fragmentation, specialization, etc.
2. Attenuation of eigen-variety: Equally significant is gaining knowledge about the factors that reduce eigen-variety. In our example, this could be operational blindness, bureaucratic obstacles or rigid habits.

[4]To frame, in a shorthand definition, is to make a mental model that enables us to make sense of new situations (Cukier et al., 2021). More extensively defined, framing is the observation or activity by which a new perspective on some part of reality is disclosed, therewith giving rise to a new meaning. The new perspective can come from a change in the apprehension of the system-in-focus or of its environment. Authoritative writings have dealt with reframing as bringing about new ways of 'how we think and make sense of the world around us' (Bolman & Deal, 2008). They have shown how strategy making is supported by 're-framing and re-perception' (Ramirez & Wilkinson, 2018), providing examples and cases that lend themselves to the analysis from the stance of variety engineering (Bolman & Deal, 2021; Normann, 2001).

So much for the 'mechanisms' of variety engineering. At this point, a methodological note is necessary:

1. Complexity/variety is relative. It denotes something subjective that resides in the (embodied) mind[5] of an observer. Let us take the example of a light bulb. For someone reading a book, it is likely to have two possible states of interest: On and Off. For an electrician, it would be at least three: On, Off and intact, Off and broken.
2. Changes in variety (of an agent, set or system) are not necessarily induced from outside. They can also come from within. For example, self-organization can be a powerful attenuator but also an amplifier. An example of self-organization as a formidable damper of complexity is given in the section on residual variety. In this case, self-organizing 'mechanisms' in the environment are used to cope with its own variety, without drawing on the system's capabilities or resources (Espejo & Reyes, 2011).

We will now present four cases on variety engineering to illustrate how it works and how it can be used to promote the sustainability of the economy and society. The first case is about ecological sustainability. It is followed by one case on each, social and economic sustainability as well as the integration of partial perspectives. Finally, the topic of residual variety is raised, and conclusions are drawn.

2 | THE ECOLOGICAL DIMENSION OF SUSTAINABILITY

2.1 | Case A: Design for self-control

This case is about variety engineering by organizational design. It starts at a huge environmental problem—the pollution of rivers and other water bodies. This is an idealized case that could be located on any one of the world's continents. We have the typical situation of a factory on the bank of a river. Here, the varieties of the regulating authority (*VE*) and the factory (*VH*) face each other.[6] These varieties are, for each of the two parties, the respective numbers of available options for action.

[5]The attribute 'embodied' emphasizes the indissoluble connection of body and mind, reason and emotion (Damasio, 1994; Varela et al., 1991).

[6]The distinction between VH and VE is defined in each case by the vantage point. If we speak of *VE* in Case A, this is the viewpoint of the state, the regulatory authority or similar, in any case not that of the company as we have it in Case B.

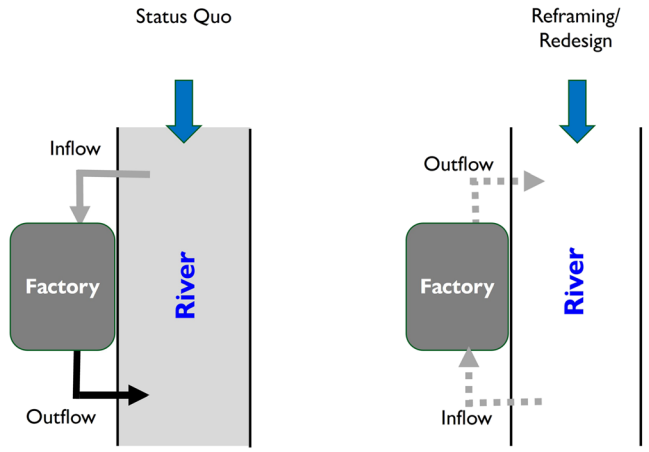

FIGURE 3 Cybernetic reframing. [Colour figure can be viewed at wileyonlinelibrary.com]

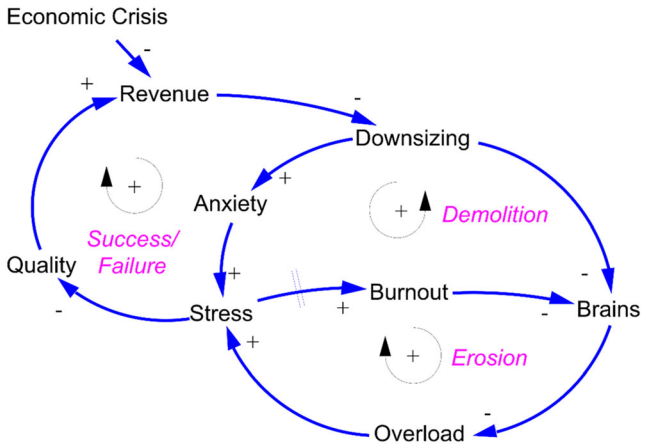

FIGURE 4 Economic crisis and culture of fear. [Colour figure can be viewed at wileyonlinelibrary.com]

Figure 3 (left) shows that the mill draws pure water from the river at the top (grey arrow) and discharges polluted water into the river downstream (black arrow): a process of pollution that occurs every day in many places of the world. What can be done about it?

Different solutions exist—prohibitions, constraints, requirements and prescriptions, etc. What we are suggesting is a reframing, that is, a reformulation of the problem in a different context than the current one. The status quo frames the problem as an issue of a question of violation, sanction and subsequent control: in short, a policing issue.

Cybernetics has a more general solution to offer: To the right in Figure 3[7] is a version based on framing that focuses on a design issue. By reversing the point of extraction and flow of the water (punctuated arrows), the factory sets up its processes so that no toxic wastewater is produced, because otherwise it becomes a victim of water pollution itself. Elegant, is not it? A reframing/redesign has created new possibilities.

The beauty of the solution is enhanced by the variety equation:

$$VH_1 \rightarrow \infty \quad (1)$$

$$VH_2 \approx 1, \quad (2)$$

where VH is the external variety, that is, the variety of the factory. In the status quo version, VH_1 is virtually unlimited. In the reframing/redesign version, the variety VH_2 roughly equals 1, that is, the factory is forced to discharge clean water into the river purely out of self-interest. In other words, the change is effective.

This is a general solution. It represents an ideal type, and therefore is not necessarily implementable, in a concrete case, exactly as shown here. However, its rationale can influence the way of thinking about this problem and possibly stimulate new approaches.

3 | THE SOCIAL DIMENSION OF SUSTAINABILITY

3.1 | Case B: Unintended side effects and how to cope with them

This case visualizes a path-dependent loss of variety of an organization, incurred by social dynamics. We start from an economic crisis of the type that occurred in 2008/2009, in many countries. A sudden collapse followed by a deep recession hit the economy worldwide. The consequences at the level of a concrete company are pictured in the causal loop diagram in Figure 4.

For the company in focus, the economic crisis entails a slump in revenue. The management's prompt response is to downsize, which it hopes will reduce costs and bring the company back into profit. That expectation is not fulfilled. A chain of unintended side-effect emerges: First, the reduction of the workforce means that 'brains walk out of the door'—the company loses knowledge and capabilities. Second, the downsizing climate fosters fears with the staff: a culture of anxiety emerges, which induces stress.

Here, a self-reinforcing and therewith destabilizing loop is started: Stress, with a delay (symbolized by two crossbars), leads to burnouts, which tendentially entail

[7]The first author owes this example to his friend and mentor Stafford Beer.

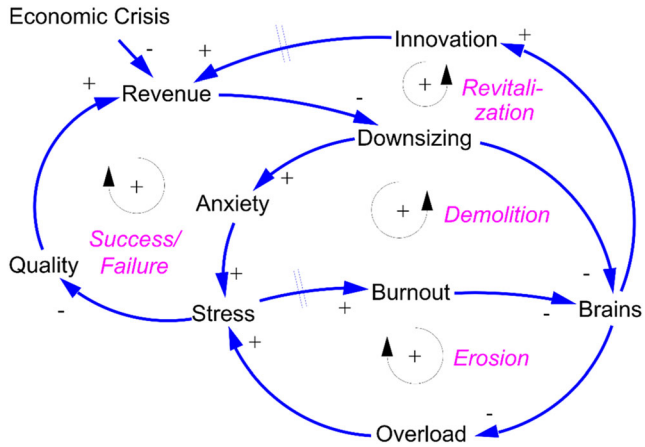

FIGURE 5 Revitalizing the system. [Colour figure can be viewed at wileyonlinelibrary.com]

losses of people. Having less staff available tends to cause overload, which again results in stress.

From here, we start the next self-reinforcing loop: Stress harms quality, particularly product and service quality. Quality is a variable that, if it grows, results in higher revenues; if it decreases revenue will be damaged. That is where we started and where we continue. The overall picture now shows a pattern of decline. An economic decision (downsizing) entails dire consequences at the social level. This worsens and the existence of the company is increasingly threatened.

By the way, the Covid pandemic led to developments that are identical with the situation described here. The pandemic led to economic recessions that were incisive for the hospitality industry, for example, in the United States, in particular Washington, DC, and in European airline companies, for example, the Swiss International Airlines AG (SWISS). Early in the crisis, sharp layoffs occurred. One year later, as Covid measures were relaxed and the tourist demand took off, these companies faced severe staff shortages. These resulted in overload, and what has been called 'great resignation', and 'great quit': Many employees left their companies and joined other industries. The shortage of skilled workers and higher costs forced companies to save on quality (Dube et al., 2021; Gössling et al., 2020; Kaufmann, 2022).

Can the fatal development be overcome? Not, or only gradually, within the structure described. The best solution would be to introduce a new loop. We are only outlining this roughly. As shown in Figure 5, focused efforts can be made in research and development that produce innovations. This could establish a new, dominant loop, change the dynamics and increase the revenue. However, there are two difficulties associated with this strategy: First, sufficient resources must be available or raised. Second, delays are to be expected between innovation and yield.

The eigen-variety (internal variety) *VE* of the company in the first phase heads toward zero: Due to self-reinforcing negative cycles, revenues decrease more and more, and thus, the space of possibilities increasingly disappears. In contrast, innovation in the second phase sets a positive development in motion, which expands the space of opportunities to one or more:

$$VE_1 \rightarrow 0 \tag{3}$$

$$VE_2 \geq 1 \tag{4}$$

4 | THE ECONOMIC DIMENSION OF SUSTAINABILITY

4.1 | Case C: Designing business systems

The design of a business system involves multiple decisions; the complexity is often overwhelming. How can a decision-maker master[8] this complexity?

A heuristic device for that purpose is the generic structure of business systems, as shown in Figure 6. The variables are logically connected to form a loop.

The diagram exhibits a structure that is generic in the sense that the dimensions and variables constituting the circuit can be identified in any business system. What varies for each dimension is its concrete design, which has to be decided specifically. For example, in a catering business, the concrete design could include options such as:

1. For the dimension *products*: complete menus, single dishes, dishes without garnish, garnishes
2. For the dimension *distribution channels*: direct distribution, franchise, specialized retail chains, wholesalers
3. Etc.

What is the variety in this design spectrum? If we take a rough approach, defining m as the amount of dimensions of design (e.g. $m = 5$ as in our example of the generic business system structure) and n as the average number of variants per dimension of design,[9] then

[8]Normally, in organizational contexts, 'mastering complexity' can only be achieved to a limited extent.

[9]*VH* in this case is the complexity of the possible designs of the business system (or potential offers) confronted by the manager, whose *VE* is his or her behavioural repertory for coping with that complexity. The gap between the two is huge.

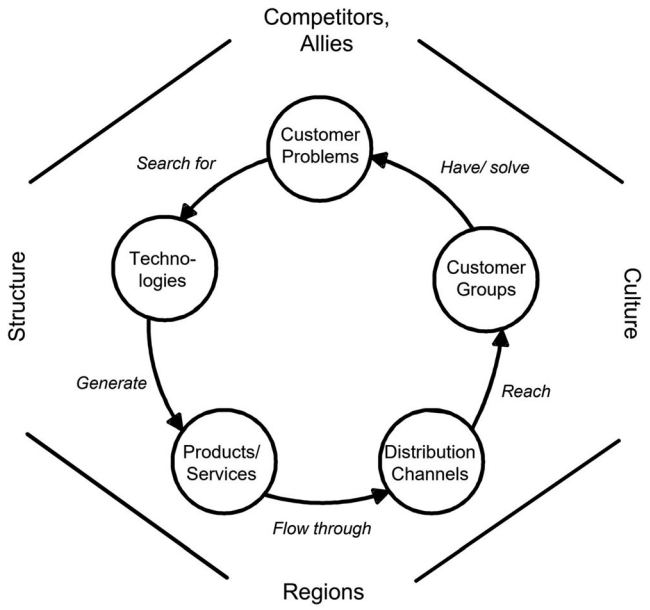

FIGURE 6 Generic structure of business systems (after Schwaninger, 2009).

$$VH = n^m \tag{5}$$

$$VH = 4^5 = 1'024 \tag{6}$$

In case the dimensions show different numbers of variants $(n_1, n_2, ..., n_m)$, the variety could be calculated similarly:

$$VH = n_1{}^* n_2{}^* ...{}^* n_m \tag{7}$$

For $n = 4$ (on average) and $m = 5$, the hetero-variety then equals 1024 different states of the system in focus, that is, the potential offers. This number illustrates that the business under study is complex. Also, the size of the variables cannot be reduced with ease. In this situation, the analytical approach taken with the calculation needs a complement: a more intuitive method of variety attenuation.

One such method is known as *morphology*. Figure 7 shows a mode of mapping the business system. We take Catering as example and extend the number of dimensions by differentiating some of those shown in Figure 6. For example, the dimension Product, in Figure 7, is subdivided in three categories (PP, PS, PL). Technologies is subdivided in three categories as well (TS, TT, TP), etc. In addition, the dimensions of competitors/allies and regions are added. In sum, now n remains 4 (on average), and m is 11. The application of the above formula (5) to the extended version of dimensions leads to a huge amount of potential states:

$$VH = 4^{11} = 4'194'304 (\text{hetero} - \text{variety, because these are the variants confronting the manager}) \tag{8}$$

After a vertiginous, exponential growth, the variety of the business system in this case amounts to more than four million different states. This is a potential variety that could handle large complexities in the market. However, it would only be effective, if the company could manage it. This is doubtful: A company that wants to offer anything to anybody is doomed. It is then necessary to find a level of eigen-complexity that can be handled effectively. What happens if we reduce some dimensions of the business system to one variant only? This would be equivalent to a powerful reduction of eigen-variety. For example, the four dimensions of price level, sales channels, region and competition could each be reduced to one variant. This would shrink the inherent variety of the system by a factor of 256–16 384 potential states (approximately 4^7 instead of 4^{11} as four of the dimensions are reduced to one state only). This would improve the ability of the company to handle the business. However, on the one hand, this reduction still would not be enough; on the other hand, such restrictions could subsequently be found to be infeasible. Here, the morphology is helpful.

There is no way of making sense here in an analytical way. An intuitive approach is to define profiles of combinations across the dimensions.

Human cognition is powerful in discerning or establishing patterns. In Figure 7 to the left, a profile is shown of the actual configuration of a business system of the company in focus. Now, it is the task of human imagination to invent and consider other profiles. The current profile of the business is more of the high quality/low standardization type. Alternatives such as a higher standardized/industrialized profile are different options, which might be examined.

In Figure 7 to the right, one strategic option is distinguished.[10] The complexity of the business system in these cases has been reduced to the extreme. Each dimension of the business system commits to a single manifestation. For example, the profile on the left defines the Complete Dishes as 'the' product. The variety of this dimension is therefore 1, no longer 4. If we continue this logic, VH will be equivalent to Equation (9):

$$VH = 1^7 = 1 \tag{9}$$

[10]One could equally compare profiles of competitors.

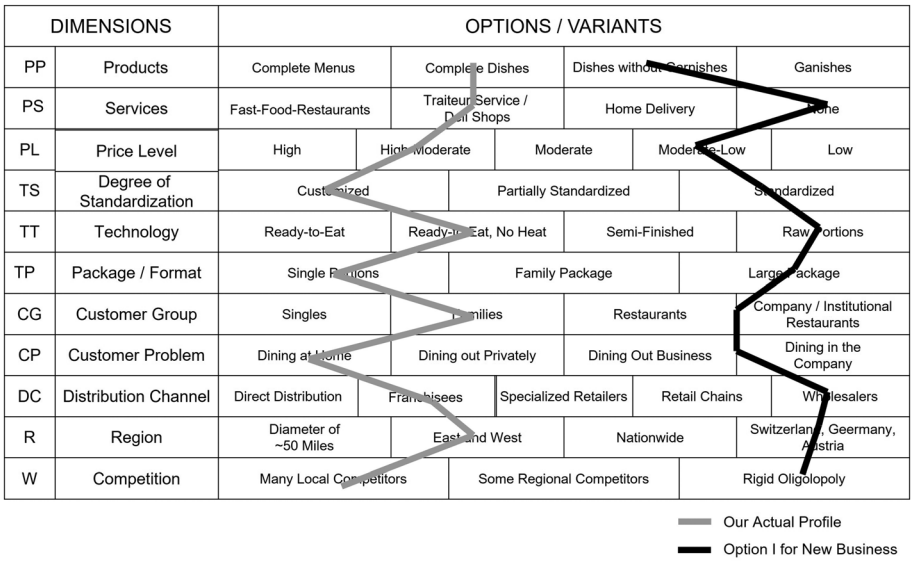

FIGURE 7 Example of the morphological method.

The potential variety VH_{pot} has been reduced from roughly four million (see Equation 6) to an actual variety VH_{act} of 1, that is, by 99.99999%. This value is merely theoretical. In reality, one could hardly uphold a business system with such a narrow profile successfully; however, the rationale of the case shows the impressive difference that can be achieved between potential and actual variety (Equation 10).

Practically, the reduction of variety will be an iterative approach, starting with the numbers of options for each dimension (n_1, n_2, ..., n_m). Step by step, these could be reduced significantly, resulting in new numbers of options $\tilde{n}_i << n_i$ (for all dimensions $i = 1, ..., m$), with $VH_{act} = \tilde{n}_1 * \tilde{n}_2 * ... * \tilde{n}_m$, and

$$\underline{VH_{pot}} \geq \geq \underline{VH_{act}} \tag{10}$$

As shown, the human intuition is able to reduce the complexity of the number of states radically, to a level that can then be handled analytically. Another way of pursuing a drastic variety reduction would be machine learning.[11]

We have to call attention to the potential downside of variety attenuation. If this goes too far, then the possible consequences can be fatal, for example, when a product range is too narrow. The ultimate case of variety attenuation is 'sheer ignorance' (Beer, 1979, p. 40).

Also the other side of variety engineering needs to be emphasized, if VH is the variety of the market and VE the variety of the firm or business. The amplification of VE can be a powerful strategy for conquering customers or markets. In principle, it would not be difficult to enhance the variety of a business system, for example, by adding additional products to the offering. The danger of this strategy would be logistical complexity. A balance should then be sought by other means, for example, by segmenting or restricting the target market.

Such an expansion of eigen-variety very soon becomes a logistic challenge. Many firms have not mastered that contest. They suffocated in the complexity of their business systems.[12] On the other hand, huge successes exist, of companies that found ways of handling the complexities of the logistics in marketing and distribution. Examples range from Amazon to eBay, Zalando and smaller specialists (Jeong et al., 2022).

5 | INTEGRAL GOVERNANCE AND CONTROL OF ORGANIZATIONS

For coping with complexity, experts advocate holistic and integrative concepts of governance and management (e.g. Beer, 1988; Bleicher & Abegglen, 2017; Espinosa & Walker, 2011). All three dimensions of sustainability covered at this point—ecological, social and economic—will be covered in Case D, under the attribute 'integral'.

[11] As we learnt from machine learning experts, there are methods that accomplish such complexity reductions. What algorithms are good at is finding correlation patterns that are useful for navigating the complex space. In the solution of the problem in focus here, techniques of dimension reduction, reinforcement learning and natural language processing would play a major role. See also James et al. (2021).

[12] One strategy to limit logistical complexification would be to seek a balance by other means, for example, by segmenting, restricting or redefining the target market.

5.1 | Case D: Corporate governance and management

The governance of organizations of any kind, corporations in particular, aims at their viability, sustainability and evolution. Two cybernetic models have been developed to support organizational governance. The viable system model (Beer, 1981, 1984, 1985) was designed for structural diagnosis and design. The model of systemic control (Schwaninger, 2000, 2001, 2009) has been developed for orientating control in the context of governance and management in general. In the following, we shall draw on the second model.

The model of systemic control discerns a logical hierarchy of control levels—the levels of operative, strategic and normative management (Figure 8).[13]

Operative management has a short-term horizon. In short, it is in charge of the current business which aims at delivering value, in terms of quality and economic success. Strategic management acts in a long-term horizon. Its task is building and cultivating value potential, that is, the prerequisites of future success. Finally, normative management is the locus of the identity and the ethos of the organization. This includes the values and supreme norms governing it. The horizon is very long, almost timeless. In the diagram (Figure 8), from below to above, complexity rises. Each one of the logical levels has specific control variables (for details, see Schwaninger, 2009, p. 48ff). An integral governance or management implies that the control parameters of all three logical levels of management are under control simultaneously, even if contradictions arise.

The eigen-variety of the management system is defined as

$$VE_t = VE_o{}^* VE_s{}^* VE_n \tag{11}$$

where the partial eigen-varieties for the levels *o* operative, *s* strategic and *n* normative, of management, multiply up to a total eigen-variety VE_t. If we assume that each one of the levels has five options of state or behaviour, the potential variety is

$$VE_t = 5^* 3^* 2 = 30 \tag{12}$$

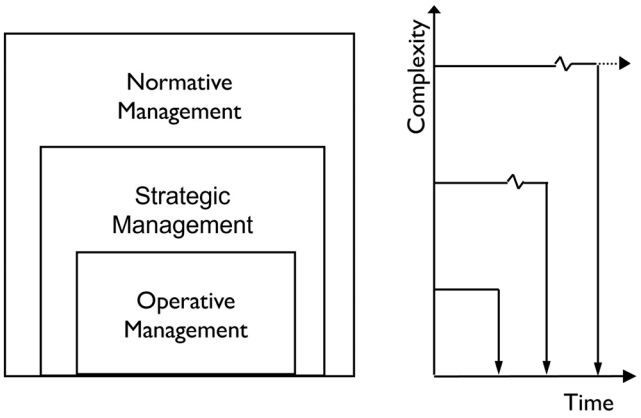

FIGURE 8 Logical levels of management in the model of systemic control.

To put this in practical terms, such options could be, for example:

1. At the operative level: Increase production efficiency, raise marketing budget, strengthen sales effort, streamline logistics
2. At the strategic level: Investment in R&D, redesign of business system, new distribution strategy
3. At the normative level: Commitment to sustainability, reorientation of focus from products to customer lifestyles

In principle, it would be relatively easy to raise the variety of the company, by increasing any one of these partial varieties. Enhancing the partial variety at only one level, for example, the operative plane, would result in a linear growth of VE_t (in Figure 9, from operations O_1 to O_3). In case of an increase of more than one partial variety, the growth of VE_t would be polynomial (e.g. from O_3 to O_5). In case of losses of partial varieties, VE_t would decrease in a similar manner (Figure 9). Generally speaking, the variation of eigen-varieties with factors k_o, k_s and k_n for the operational, strategic and normative levels leads to a modification of the total eigen-variety:

$$VE_t = VE_o{}^* k_o{}^* VE_s{}^* k_s{}^* VE_n{}^* k_n, \tag{13}$$

In Figure 9, for example, we have $k_o = 1.2$ (for VE_o between O_1 and O_2 for the increasing scenario) and $k_o = 0.8$ (for VE_o between O_1 and O_2 for the decreasing scenario). Equation (13) shows that the modification of variety on one level only leads to a linear change, the modification on two levels to a quadratic change. In practical terms, concerted simultaneous increases of variety,

[13]The model of systemic control (Schwaninger, 2000, 2001, 2009) has utility at all levels of management, including corporate governance, which it subsumes that is the system of rules, practices and processes by which a firm is directed. It involves balancing the interests of a company's many stakeholders (Chen, 2021). Corporate governance is mainly located at the level of normative management, and for the organization as a whole.

	O_1	O_2	O_3	O_4	O_5	O_6
VEo	5	6	7	7	7	7
VEs	3	3	3	4	5	5
VEn	2	2	2	2	3	4
VE_t	30	36	42	56	105	140
VEo	5	4	3	3	3	3
VEs	3	3	3	2	1	1
VEn	2	2	2	2	1	0
VE_t	30	24	18	12	3	0

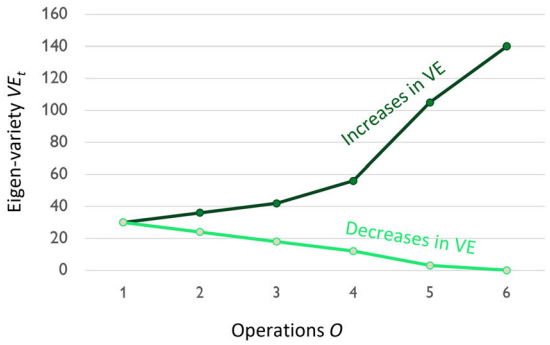

FIGURE 9 Changes of total variety as a function of changes in partial varieties (upper part: increasing partial varieties; lower part: decreasing partial varieties). [Colour figure can be viewed at wileyonlinelibrary.com]

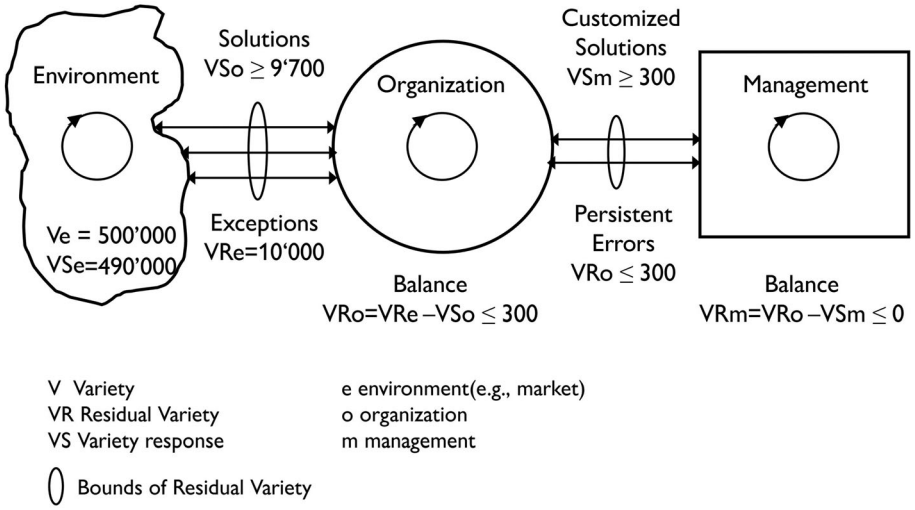

FIGURE 10 Stages of residual variety.

that is, of the respective number of choices, at more than one level, enable an exponentially stronger radius of action. One has to keep in mind that the changes of numbers on the different logical levels of management (operative, strategic, normative) can also compensate each other with respect to VE_t in case there is an increase on one and a reduction on another level.

To summarize, considering the three management levels (operative, strategic, normative) and their options for action (eigen-varieties) in an overall view, then the total variety VE_t is the product of the partial varieties, since these are combinations in the sense of combinatorics. A change of the partial variety in only one dimension has a linear effect on the total variety, since only one variable is affected. An increase in more than one dimension typically leads to a super proportional increase of the total variety (amplification); a decrease in more than one dimension leads to a sub-proportional decrease of the total variety.

The data and the picture indicate that variety engineering has a non-linear tendency (in case of an increase in variety of more than one level), whereby amplification deviates more from linearity than attenuation, which remains closer to a linear behaviour.

6 | THE CONCEPT OF RESIDUAL VARIETY

At this point, it makes sense to introduce a conceptual distinction between three entities that cope with complexity and interdepend at the same time (Figure 10).[14]

The three entities are environment, organization and management. Each one of these entities copes with the specific complexities it is confronted with. Each one of them absorbs complexity by means of self-organization. There is a remnant complexity it cannot take care of. This residual variety has to be absorbed by an upstream unit, the organization for the environment and

[14]The concept of residual variety and the diagram go back to Espejo (1989). The equations come from the authors.

TABLE 1 Summary of the outcomes of different strategies of variety engineering.

	Success	Failure
Amplify eigen-variety	Reframing/redesign of strategies and structures Strategic focus Innovate (Case B) Increase power of marketing through new products (Case C) Flexible management (Case D)	Overstretch amplitude of product range (Case C) Become dominant in a way that jeopardizes the relationship with the environment
Attenuate eigen-variety	Keep the set of strategic and structural options focused (Case C)	Lack of flexibility in management (Case D)
Amplify hetero-variety	Understand drivers of complexification in the environment (market, regulation, etc.)	Inability to cope with variety proliferation in the environment
Attenuate hetero-variety	Modelling and structuring the environment and the organization Reframing/redesign of strategy and structure (Case A)	Limitation of co-evolution of the interacting agents

the management for the organization. To illustrate that principle, we draw on a somewhat abstracted practical example.

We refer to a firm running an online business in its market. The market shows a complexity of $V_e = 500\,000$ transactions. Most of these transactions are realized within the market itself and without any interference by the organization. This self-organizing property is represented by the loop icon in Figure 10, indicating the variety response $VS_e = 490\,000$. Two percent of the variety—10 000 standardized transactions—is not attended inside the market and needs special attention by the organization, which equals the residual variety $VR_e = V_e - VS_e = 10\,000$. The organization needs to take care of these exceptions and is successful in 97% of the cases ($VS_o = 9700$), while the rest—300 cases of persistent errors, which cannot be attended by the organization—needs the attention of the management, which, again, equals the residual variety $VR_o = VR_e - VS_o = 300$. The management is supposed to come up with customized solutions, which often imply some sort of (partial) redesign of procedures, changes in the product range, etc. The management is successful if it can offer at least these 300 solutions, that is, $VS_m \geq 300$, which means $VR_m = VR_o - VS_m \leq 0$ and no problem remains unsolved. The equations in Figure 10 contain inequality operators. This expresses the fact that the balance can assume a negative value when a variety surplus occurs. If, for example, the variable VS_m is, let us assume $VS_m = 350$ (instead of 300), then the balance $VR_m = -50$. This result indicates a redundancy of potential command (Beer, 1981; McCulloch, 1989).

7 | CONCLUSION

The goal of this paper is to elucidate ways of dealing with complexity through variety engineering. We defined the concept and explored the role of variety engineering. In addition, we demonstrated how it works by means of examples of attenuation and amplification as strategies for coping with complexity. The substantive horizon has covered the different dimensions of sustainability—ecological, social and economic, as well as the overarching aspect of an integral governance, which covers all of these dimensions.

We have demonstrated that both approaches, attenuation and amplification, can be a blessing: They can lead to an equilibrium of varieties between competing or conflicting agents. At the same time, we have indicated that any one of these strategies can also lead to failure.

Our emphasis has been on the enhancement of eigen-variety and the attenuation of hetero-variety, but we have also considered the other two options: attenuation of eigen-variety and amplification of hetero-variety. An overview is given in Table 1.

We do not claim completeness for the successes and failures listed in the table. The cases presented are only some examples from the universe of manifestations of variety engineering. But these are typical for the topic, lending themselves to a modest generalization.

The enhancement of eigen-variety can lead to remarkable successes. The most powerful approach in that category is reframing/redesign of structures or strategies. The main failure we have referred to is the collapse of eigen-variety of a business when the complexity of the offering was overstretched.

Raising eigen-variety is often achieved by focusing, specializing or shrinking the business. In these cases, a change of variety is implied for both sides of the equation, *VH* and *VE*. *VE*, seen superficially, may be reduced as a function of a loss of 'mass', as is the case in downsizing. However, the main point is that the environment is redefined. It tends to become smaller and less complex. Henceforth, the relative variety VE/VH shifts in favour of the business, which then has a better grip on the market.

Successful attenuation of hetero-variety hinges on an understanding of the structures inherent in the system of interaction. Building and implementing good models here is key—reframing/redesign of strategy and structure probably being the most powerful lever. Excessive damping can lead to failure if strong resistance to the dominant party arises from the environment, respectively, if the coevolution of the actors involved is made impossible.

The most powerful lever with both approaches—enhancement of eigen-variety and attenuation of hetero-variety—is framing/redesign.

The potential variety of a complex system does and cannot be materialized fully, with all its states or behaviours. Management is the process by which the desirable states and behaviours of a system are enabled, while the undesirable ones are prevented. As we have shown, variety engineering is a powerful yet subtle vehicle for accomplishing this delicate endeavour.

What would need further elaboration to complement the cases treated here is the dynamics of variety engineering in organizational processes. The equations and numbers used until now are very abstract and would be insufficient to describe these processes in a qualitative sense. Variety amplification and attenuation in organizations are the product of communication and conversations.[15] We can think, for example, of conversations for reflection on the one hand, and conversations for action, on the other. These dynamics of variety engineering are an important topic in need of further investigation.

In addition to the demonstration of how it works, it is necessary to emphasize in this conclusion what variety engineering can mean in the future. It is an unorthodox conceptual approach that is effective in confronting complexities. It can, for example, guide decisions and actions in conflict situations. Its working principle may seem too simple. However, this principle is a platform for inciting innovation. It can stimulate inventive, and sometimes radical, design of complex systems—when it comes to reframing or transformation. And it can foster the resilience needed for dealing with the ubiquitous uncertainty. Variety engineering has great potential!

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[15]For the distinction between the concepts of communication and conversation according to Shannon & Weaver, and Pask, see Dubberly & Pangaro (2009, p. 1f). The relevance of these concepts from the stance of the 'new' cybernetics, for example, Maturana (1997), Winograd and Flores (1986) and Luhmann (1995), is analysed in Vásquez and Benavente (2016).

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