Methods of analysing the mechanical state of trees: linear scales and antifragility

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Methods of analysing a tree's mechanical state are used to categorise and qualify its condition.

These tools, which are employed to diagnose structural condition and allocate a safety factor,[1] all have a common purpose: to make objective what is subjective. In order to categorise this state, rating scales are usually used.

Linear scales

The emergence of the ARCHI physiological and ontogenic[2] diagnostic method (Drénou, 2010) has called into question linear scales of assessment (Figs 1 and 2). Woody plants are by nature complex systems made of interdependencies and non-linear reactions. These reactions to stresses and interdependencies prohibit a representation of the effects on a straight line (linear scale), but they can be shown as a curve (often exponential), and sometimes as a dynamic circle allowing a return to normality (initial state), or even, for some, to a condition considered superior to the initial state. This improvement following stresses and strains is a common phenomenon, even a standard feature, of complex systems including living organisms.

Antifragility

Some complex or living systems are able to take advantage of accidental events and unpredictable shocks rather than suffer as a result of them. It is not about healing, fixing, or antidotes to these events; it is about a fundamental necessity related to the resulting benefits of improvement in these systems, which is referred to as *antifragility*.

Fragile systems (by semantic opposition) suffer as a result of hazardous events. Indeed, no static object or material will be stronger after hitting the ground or being stressed beyond its elasticity limit. They are described as fragile because their mechanical strength threshold is lowered when they are exposed to too much stress, resulting in structural damage. They cannot take advantage of such events. A fragile system will therefore always become more fragile, and will suffer as a result of hazardous events.

Robust materials are more resistant. They can be exposed to high levels of stress, and some are more or less sensitive to it. But their robustness will not increase after such events. Only learning, antifragile systems benefit from chance and serendipity, and improve throughout their lives if pushed to do so. Challenged, they become more and more efficient.

Here are some natural antifragile examples we all know: ecosystems, social insects and living organisms in general; and some artificial antifragile examples: computer systems and some economic systems.

Trees: a learning system

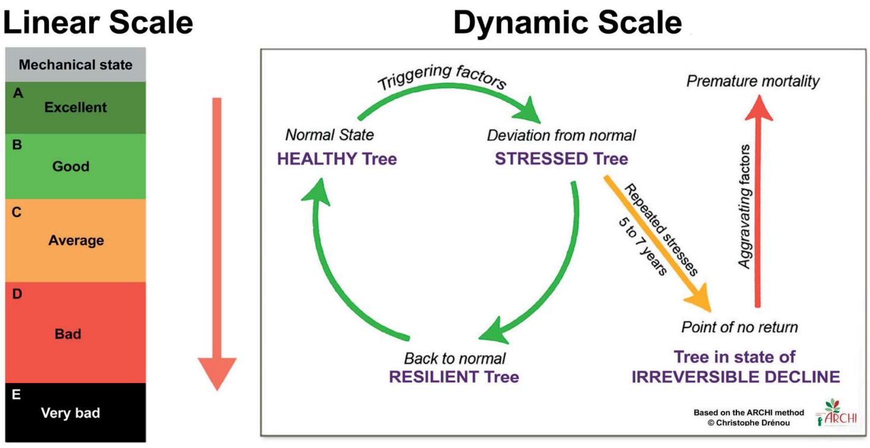
Trees have the ability to sense and react to temporary stimuli (mainly wind). This phenomenon is called thigmomorphogenesis, or mechano-sensing. Thus, for a tree, the consequences of gusts of wind are multiple and favourable over time because they facilitate the optimisation of its intrinsic safety factors thanks to:

- inhibition of primary growth (in height);
- increase in branch and trunk diameter;
- changes in shape;
- an overproduction of anisotropic[5] reaction wood; and
- root growth.

Thus, a healthy subject is tuned to its environment and mechanically improves its safety coefficient over time. An average tree has a safety factor of between 4 and 5. But very old trees with excellent slenderness factors (less and less tall but with a larger and larger diameter) can have a safety factor of up to 20, sometimes 50: they increase this factor by 3% with every 1% increase in diameter by exponentially improving their height/diameter ratio (Fig. 3).

These trees often have very large cavities, sometimes with a minimal residual shell wall, but even with the loss of a percentage of safety due to the presence of these features, they still have a safety factor well above the average for trees without these features and of smaller diameter. The assessment scale is therefore not linear in these cases: it will be an exponential curve, moving not towards fragility but towards antifragility, improving well beyond the initial state.

However, it should be noted that the responses of antifragile systems generally require a period of adaptation, and for trees this can sometimes be long. It should also be noted that every system has its own limitations, and that even complex systems can suffer irreversible damage (primary failure). The notions of antifragility, reversibility and temporality therefore considerably complicate structural diagnosis and call into question



Figures 1 and 2: Two types of condition grading scales – linear[3] and dynamic.[4]

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[1] The safety factor is defined as the ratio of the load-carrying capacity of a structure to the actual load experienced by that structure. In simpler terms, it can be thought of as the safety margin available to a structure in relation to the stresses typically encountered. For a tree, the safety factor depends, in particular, on the wind load, the height of the tree, its diameter and the properties of the wood.

[2] Ontogeny: the development or course of development of an organism.

[3] Based on the ITD scale (Integrated Tree Diagnosis: Moore, 2003). This method is based on a linear scale but allows for the possibility of negative or positive changes in the identified features.

[4] Based on the ARCHI dynamic scale (Drénou, 2010).

[5] Anisotropic substances have a physical property which has a different value when measured in different directions. For example, wood is stronger along the grain than across it.

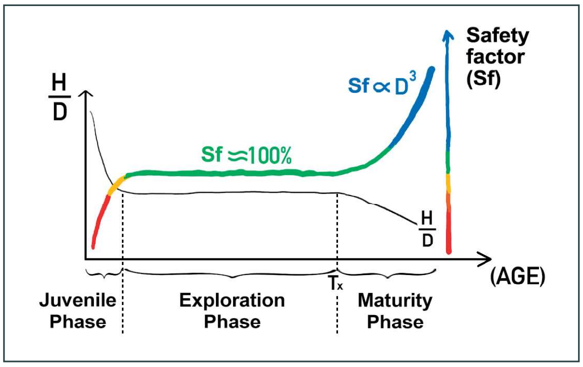

Figure 3: Exponential improvement of the safety factor throughout the life of the tree. The increase of the basic safety factor proportional to D^3 is only happening after the point in time when the tree has reached its maximum height – not before. The basic safety factor is not taking into account any features that may lower the load-carrying capacity but just the size of the cross-section and thus, for a cross-section with this type of features, this basic safety factor has to be multiplied with a factor (100-StrengthLossDueToFeaturesInPercent)/100). (Based on Rinn, 2021)

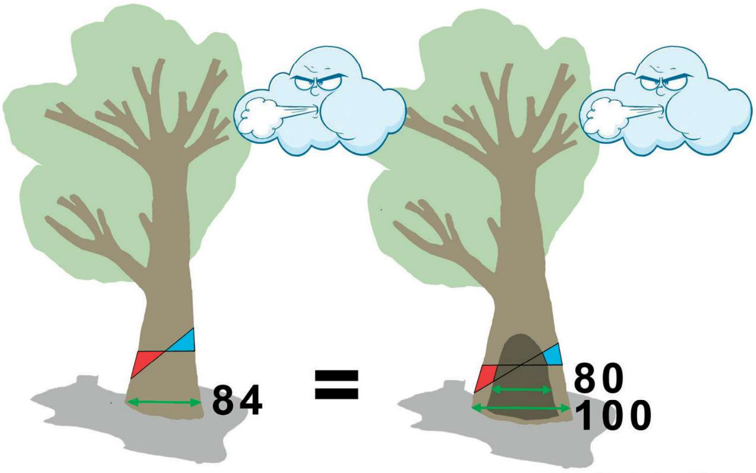

Figure 4: The tree on the left is intact with a diameter of 84 cm. The tree on the right has a diameter of 100 cm, but a shell wall thickness of only 10 cm. Both trees are equally resistant, i.e., they can withstand the same wind loads. (Illustration: Trouillet & Dambezat, in Drénou, 2021)

the value, or even the possibility, of giving an opinion at a given moment without a supported and clinical reading of the subject's reaction dynamics.

Increasingly resistant trees

If trees are antifragile and can therefore improve, it seems necessary to accept that a subject with slow-developing long-term symptoms can sometimes be stronger than a tree of smaller diameter without those symptoms. So, for example, a 100 cm diameter tree with a symmetrical 80 cm cavity will have the same load-carrying capacity as a solid tree of 84 cm diameter. They will be equally resistant and therefore able to withstand equivalent loads.

The tree with the cavity in Figure 4 could achieve a grade of A (excellent) on a linear scale and even higher on a dynamic scale despite its obvious features, often described as 'defects'. The same applies to a tree with an open cavity significantly compensated by cambial columns, as these reinforcements provide increased resistance to torsion and greatly improve the biomechanical behaviour of tubes under stress. This is even more true in the presence of a strong geometrical modification of the root plate in the case of underground fungal colonisation. Very old trees with large trunk diameters have such high intrinsic safety factors that it is almost always unnecessary to try to actively manage them.

These ideas can explain what we all observe every day in nature: trees with cavities and other significant features manage to pass through storms without too much damage, whereas intact trees fail. Should we consider these observations as abnormalities, or should we change our paradigms and accept that the criteria and mechanical scales we generally use are now obsolete? This new paradigm could change our view of not only the biomechanics and what we currently call the defects of a structure, but also the incidence of fungi, which in fact seem to be capable of actions that are beneficial to the durability and resistance of plants by forcing them to respond and develop antifragility.

How do we categorise a mechanical state?

The possibilities of resilience do seem to be better accepted and integrated in physiological diagnosis today, so could mechanical diagnosis also be inspired by the dynamic scale of the ARCHI method, incorporating the possibility of mechanical optimisation, or mechanical resilience, and of a return to normal (the initial state) or even beyond it?

Combined approaches should be considered in order to move away from linear scales and better take into account the complexity of tree safety factor assessment. In many disciplines (mainly medical), a number of methods are now available to combine symptoms and signs using tools such as matrices or clinical predictive rules (CPR). Many medical scales attempt to evaluate the progress of a problem by integrating a certain number of symptoms associated with a pathology with an individual gradation of their severity. Each year, about 10,000 scientific medical articles relating to clinical predictive rules are published. Thus, they are considered worthy of the greatest attention and their usefulness in medicine is no longer in question, as long as practitioners use them where they are relevant and as a complement to a rigorous clinical approach.

In order to move towards more methodical practices in diagnosis and diagnostic training, arboriculture could take up clinical predictive rules, too.

Translated from French by Olivier Dambezat. Proofreading and editing by Sarah Bryce, Simon Richmond and Mark Buglioni.

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References

Drénou, C. (2021). *La taille des arbres d'ornement*. CNPF.

Drénou, C., Caraglio Y. (2019). *'Parlez-vous Archi?: les principales définitions de la méthode Archi*. Forêt Entreprise, Forêt Privée Française.

Ellison, M. (2020). *Practice Note: Quantified Tree Risk Assessment*. QTRA Ltd.

Herzig, L., Mühlemann N., Bischoff T., Favrat B., Gencer B. (2011). *Développement, implémentation et utilisation pratique d'un score diagnostique*. Revue médicale suisse (revmed.ch).

Moore, W. (2003). Diagnostic intégré de l'arbre. Une méthodologie pour le diagnostic de l'arbre. *Arbres et Sciences* 3(10).

Rinn, F. (2011). Basic aspects of mechanical stability of tree cross sections. *Arborist News* (February): 52–54.

Rinn, F. (2013). Shell-wall thickness and breaking safety of mature trees. *Western Arborist* (autumn).

Rinn, F. (2021). *Allometric Self-referencing (ASR) for Tree Safety Evaluation*. ArboSpectrum.

Schwarze, F. (2008). *Diagnosis and Prognosis of the Development of Wood Decay in Urban Trees*. Rowville.

Taleb, N. (2013). *Antifragile: Les bienfaits du désordre*. Broché.

Trouillet, P. (2022). The clinical model. *ARB Magazine* 197 (summer): 36–38.

Trouillet, P. (2022). Échelle linéaire et scores cliniques prédictifs. *Lettre de l'Arboriculture* 104 (January/February).

Union régionale des professionnels de la santé *'les échelles d'évaluation et les classifications'*: www.urps-infirmiere-paca.fr (accessed 23/5/23).

Wessoly, L., Erb M. (2016). *Manual of Tree Statics and Tree Inspection*. Patzer Verlan.