NOTES ON URBAN TREE STRUCTURE MANAGEMENT

Gabriel Iguiñiz Agesta – www.arbolonline.org -

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Reviewed March 2007

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Introduction. PRESENTATION, OBJECTIVES AND CONTENTS OF THIS WORK.

Broadly speaking, our pruning concepts and techniques have been inherited from a time in which pruning was understood as the obvious way of controlling and directing the structure of a tree. The tree would then be limited to responding obediently to the pruning interventions.

In recent years, various studies have brought to light interesting information about structural development and therefore, our relationship with pruning.

- Alex Shigo revealed to us the laws of decay development in live wood and, consequently, the relationship between large wounds and widespread decay. With Alex Shigo, we learned that wounds and large pruning cuts (heading cuts, topping…) lead to serious decay in the tree structure.
- Hallé and Oldeman discovered that the structural development of different species is subject to determined laws and models, which vary from one species to another. These architecture models determine precise forms of ramification and development, especially in early development.
- Pierre Raimbault shows us that, in spite of these different architecture models, there is a common model of structural development, from germination to old age, for all tree species. Therefore, development of the tree structure, whether pruned or not, apparently isn't chaotic but follows laws that can be studied.
- Finally, we must consider the tree's own state of vitality (this aspect is also partly considered by Pierre Raimbault), for its influence on development and on the effects of pruning.

The structural development of both young and adult trees is very complex and probably not completely understood yet. In this work, we will avoid going into complex concepts and will limit ourselves to the minimum elements necessary to discuss practical proposals

In any case, this text isn't intended to be used as a manual for pruning and structural formation. It only seeks to bring together a series of considerations and reflections about what we do with trees, how they react and why, all of which constrained by the current limitations of our knowledge, which are many, as well as the author's own limitations, which are even greater.

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Chapter 1 describes Pierre Raimbault's natural development model, which will be refered to often in this text.

Chapter 2 is dedicated to the concept of the urban tree and its structure based on Raimbault's model. Emphasis will be placed on the presence or absence of authentic lateral branches (as defined by Pierre Raimbault) and the presence or absence of an area of defense against decay at the base of these branches (as defined by Alex Shigo).

Chapter 3 discusses several other themes not strictly covered in the works of Shigo and Raimbault, but that must necessarily be considered.

Chapter 4 focuses on planting as well as the development and conditions of the plant, explaining the process the plant goes through in the nursery and in its plantation in urban soil, the consequences of this on its vitality and later structural development.

Chapter 5 focuses on structure management. With this concept, the intention is to relate the development process of the tree structure throughout its life, where pruning is one of several significant factors, along with less considered (although very active) aspects such as vitality, cutting of the lead branch in the nursery, transplant shock, etc.

Chapter 6 analyzes the relationship between pruning and the fitosanitary state of trees.

Finally, chapter 7 discusses a series of conclusions.

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Original texts by Pierre Raimbault appear in italics. Graphics of the phases are his. Alex Shigo's work is published and widely known. The remaining is the author's personal contribution and interpretation.

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Chapter 1. NATURAL DEVELOPMENT OF THE TREE STRUCTURE.

In a tree we can make a distinction between outer shape and structure. The outer shape is the result of the exterior volume of its crown and trunk (what we see when we look at a tree with all its leaves). The structure is the specific arrangement of the trunk and branches of a specific tree. Trees with identical outer shapes may have different structures.

1.1. Structural models by Hallé and Oldeman.

There is plenty of information that will not be detailed here derived from the works of F. Hallé y R.A.A. Oldeman, in which the specific development models of different tree species are described, defining 22 architecture models according to modes of growth, ramification and differentiation of aerial axes.

Control of these architecture models seem to be genetic and seems to act on some species throughout their whole life, although they usually do so in the earlier phases.

We will discuss this again in the chapter about sprouts and shoots.

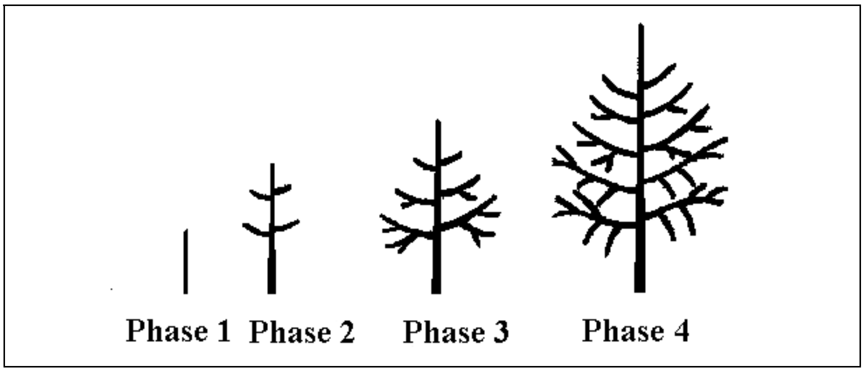
1.2. Natural development according to P. Raimbault.

Pierre Raimbault describes how, regardless of specific architecture models, natural development in all tree species goes through a series of phases or stages from germination to death by old age in centennial trees. He proposes a 10 phase model.

The following is the translation of an original text by P. Raimbault, and its corresponding diagrams.

"Natural development, according to P. Raimbault.

The life of a tree from germination until death may be divided into 10 stages. This scale is applicable to all ramified trees.



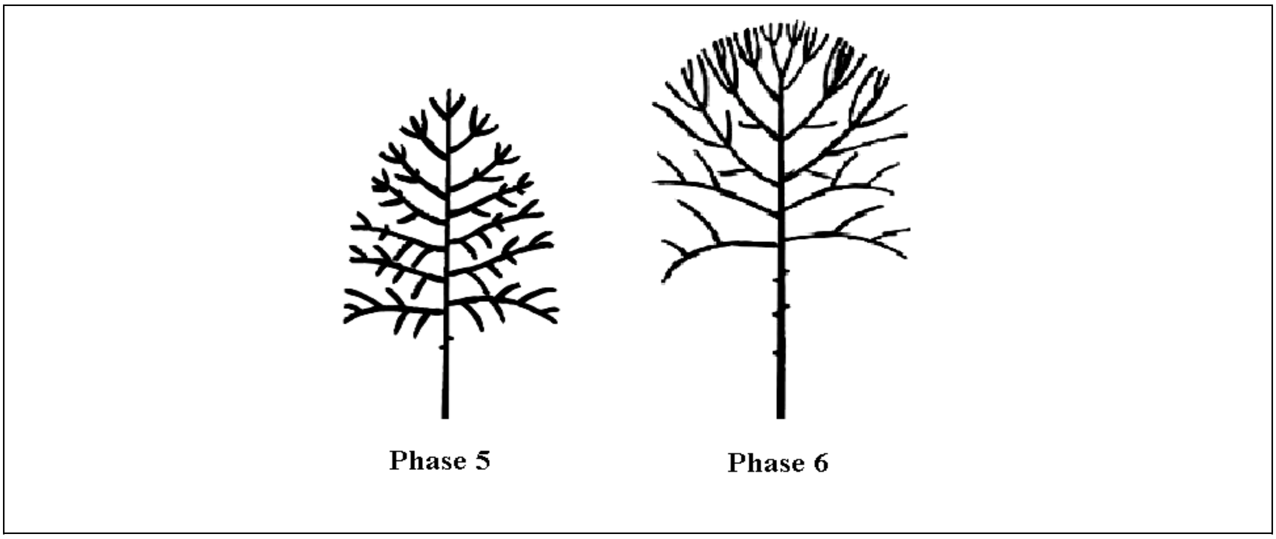
Throughout the first 4 phases, the plant elaborates the trunk and temporary crown, which develops in a hypotonic mode, under a strong apical dominance.

In phase 1, the trunk is elaborated without ramifications. If the terminal bud dies every year (depending on the species), the subterminal retakes the function of extending the trunk.

In phase 2, the trunk presents only short sprouts that function like leaves.

In phase 3, the trunk already has branches with all the levels of ramification, under a strong apical dominance. Growth of these lateral branches is more or less horizontal and they tend to ramify from the lower face (hypotonic).

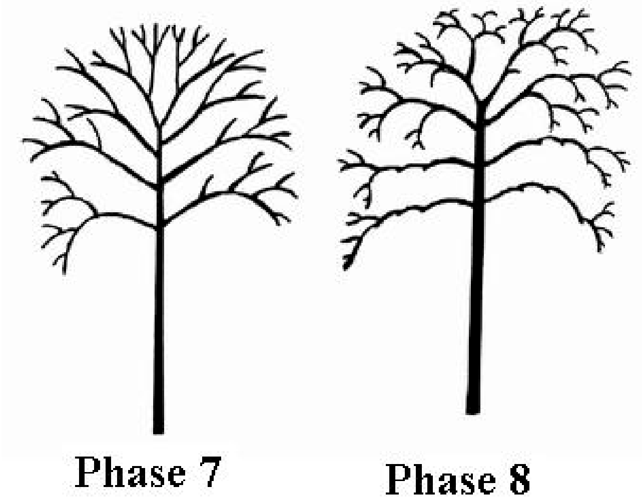
In phase 4, the lower branches and extremities of the higher branches start to escape from the apical dominance and to lose their hypotonical development mode. The selfpruning of lower branches begins. At the end of the 4th phase, weakening of the apical dominance begins. All ramification elaborated under the apical dominance constitutes a temporary crown that is destined to disappear in the mid term.



During phases 5 and 6, the branches that have become independent' reiterate themselves' indefinitely, ramifying under an isotonic mode: the tree elaborates its definite structure.

In the 5th phase, the arrow is still morphologically visible and the temporary crown still amply covers the trunk. The branches initiated during the disappearance of the apical dominance or shortly before become independent and now constitute the definitive crown. The extremities of these branches start to develop in all the faces (isotony).

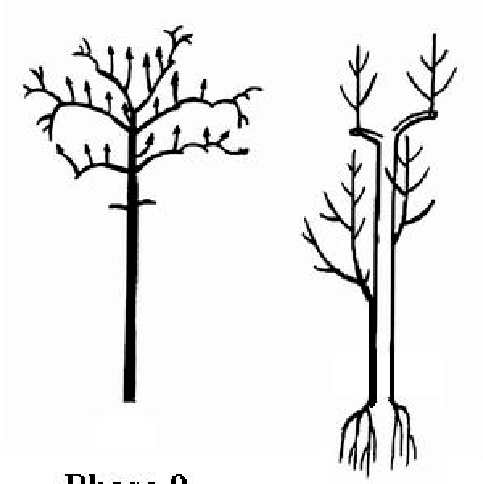
In the 6th phase, the temporary crown which is still very present starts to prune itself progressively from bottom to top. The definitive crown, formed by a set of equally important branches, becomes round and the isotony becomes general. Each of these branches reproduces the development that has occured in the trunk: first an apical dominance that only allows the formation of weak, dominated lateral branches, then this dominance weakens to allow the development of stronger lateral branches, and finally the dominance disappears, opening the structure into two or three equivalent branches, etc.



During phases 7 and 8, the tree maintains its crown's volume, partially renovating its branches under an epitonic mode.

In the 7th phase, the tree has reached full maturity. The trunk is completely naked and only the definitive crown remains, which progressively reaches its final volume. At the base of the main branches, branches located on the lower face and the old vigorous hypotonic branches lose their vitality and end up dying (first type of mortality). Strong ramifications develop on the upper part of the structure (epitony) from already existing or recently formed branches, progressively renovating the principal axes, which end up dying (second type of mortality). On the structure, the ramifications born under strong apical dominance are first to die while those born under weak apical dominance disappear later on (third type of natural mortality). Thus a simplified ramification system is established (according to a fractal system), densely ramified on the outside. The tree reaches its maximum development.

In the 8th phase, apparently identical to the 7th, the progressive degrading of the root system weakens the aerial part. The annual sprouts don't produce more leaves than those already formed in the buds before emerging, and no new ramifications are produced in the extremities. The branches partially renew themselves, not in their extremities but from more internal zones (epitony and basitony in the crown).



During phases 9 and 10, the crown descends and the tree folds into more interior positions.

In the 9th phase, the crown reduction begins, preceded by and originating in the degradation of the root system. The tree can't maintain the volume it reached at the height of the previous phases: mortality in the crown is superior to the renewal capacity and begins to affect the more important peripheral branches. This mortality is preceded by the appearance of more and more powerful shoots on the structure and, finally, on the trunk. Generally, the tree dies or falls at this point.

In phase 10, (which only a few trees reach) the tree sinks into itself. The crown completely dies. Strong shoots appear on the trunk. These buds become progressively more independent from the whole of the tree, forming columns along the trunk and developing their own root systems.

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1.3. Glossary of terms used by Raimbault.

- Apical dominance: the terminal bud exerts a dominance on the axilar buds, meaning that they inhibit their growth. Also, the central axe of the young tree controls the growth of inferior lateral branches. In a wider sense, the whole of the crown subordinates the inferior branches.
- Hypotonic development: when, as a consequence of a strong apical dominance, the sprouts of the inferior face of a plagiotropic branch develop more strongly than those of the superior face.
- Epitonic development: when. by weakening or absence of apical dominance, the buds of the superior face of a plagiotropic branch develop with more strength than those of the inferior face.
- Isotonic development: when the ramifications develop with equal vitality, indepently of their orientation, for example the ramifications that emerge from a vertical axe.
- Plagiotropism: it's the more or less horizontal growth of the lateral branches under an apical dominance.
- Short sprouts: those derived directly from the existing organs in the bud from which they are coming. Few leaves and short internodes are produced. (Large sprouts: when the bud opens itself, the terminal meristem is activated and many leaves and large internodes are produced).

1.4. A few considerations about P. Raimbault's model.

Raimbault's model is obviously a simplification, but a simplification that emphasizes general development rules with interesting practical applications.

1.4.1. Development conditions of the tree-type.

Raimbault's tree-type represents the development of any tree species in its natural environment or forest: in other words, an optimal environment (soil, humidity, climate...), direct sprouting from the seed, emerging from a tap root, maintained vitality, first growth in mass and clarification of the mass.

Even in the best real examples, Raimbault's model isn't followed in a linear way but there can be ups and downs, receding, etc., with expansions, stagnations and even receding of the crown development.

Raimbault's model only represents the development of the ideal, optimal tree, although understanding this model helps to understand the structural development of specific cases.

In an urban environment, the conditions are very far from being optimal, especially when roadside, and later we will look at the development of the urban tree.

1.4.2. Tree development and vigor.

It is fundamental to understand the importance of vigor in the development of tree structure. As mentioned before, Raimbault's model is based on the assumption of a high, maintained vitality.

What defines tree species is the forming of a unique, straight and vertical axis: the trunk. But species differ from one another by their more or less marked tendency to form a straight, high trunk (according to architecture model and development mode of each species), although within each species, vigor helps to form a clear trunk while the absence of vigor leads to trunks becoming twisted, bent or crotched . In fact, there isn't a defined frontier between trees and shrubs, and numerous tree species include shrub varieties.

The fact that, for the sake of functionality, we choose trees with "good trunks" to plant in forests or in urban arboriculture, means that we are surrounded by species whose architecture model and growth habits favor the forming of a clear central axis. But we mustn't forget that there are other ways of being a tree, other models, other tendencies, even in the species that surround us.

In some species, a weakening in vigor causes an increased tendency of the extremity of the axis to open up into one or more crotches from an early age, in other words it causes the premature appearance of elements belonging to an adult crown. Even if vigor is then recovered, the crotch or crotches will stay and become a part of the definitive structure.

And so vigor appears to be fundamental in the formation of the structure. Its presence or absence and highs and lows determine the structure, which in turn give us a register of the vigor of a tree throughout its life.

In any case, episodes of lack of vigor are not taken into consideration in Raimbault's development model. In this work, we will study weakenings and their consequences in the chapter about the altered development of the urban tree.

(Generally, "vigor" is understood as growth energy, and we qualify as vigorous those specimens that grow with strength. We could review this concept of "vigor" and, in fact, for A. Shigo, vigor is exclusively a specific capacity (particular to species) to overcome pressure and agressions from the external environment. Therefore, for Shigo, there is no need to talk about more or less vital individuals or of more or less vigorous moments in an individual, but of more or less vigorous species.).

1.4.3. Crotches caused by traumas or accidents.

During the young tree's development, there can and usually will be quite frequent traumas or accidents (frosts, etc.) that may cause the death or disappearance of the terminal guide without the occurrence of any notable weakening. In these cases, an apical crotch may appear, which through vigorous growth can come to form a double crown (or more rarely, a multiple crown).

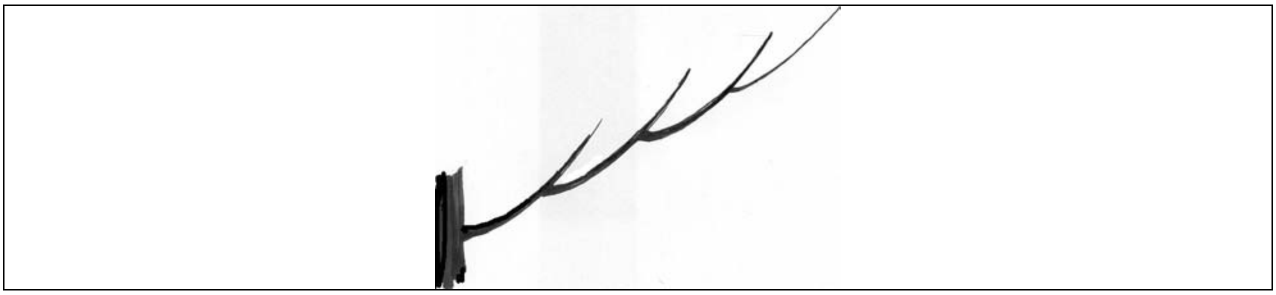
Note that the presence of vigor produces only one crotch, not various successive crotches as we will see later on, which are produced by crisis weakness.

1.4.4. Definition and behaviour of the lateral branches.

According to Raimbault, we define lateral branches as only those ramifications that appear laterally from a vigourous vertical axis, imposing a clear apical dominance, (Phase 3).

Once the lateral branches have been formed, the apical dominance of the vertical axis that makes them subordinate causes these lateral branches to:

- Develop forming a certain fixed angle in relation to the trunk, and that
- The sprouts that emerge from these lateral branches do so from the lower face. This is called "hypotony". In any case the manifestation of hypotony is quite different from one species to another.



However, if the lateral branches remain while the apical dominance weakens or disappears (phases 4 and 5, traumatic loss of the guide or declining vigor), we will see lateral branches that stop behaving as such in terms of horizontality and hypotony: their extremities will grow vertically and if these extremities continue to develop, they will do so in every direction (isotony) like in phase 5.

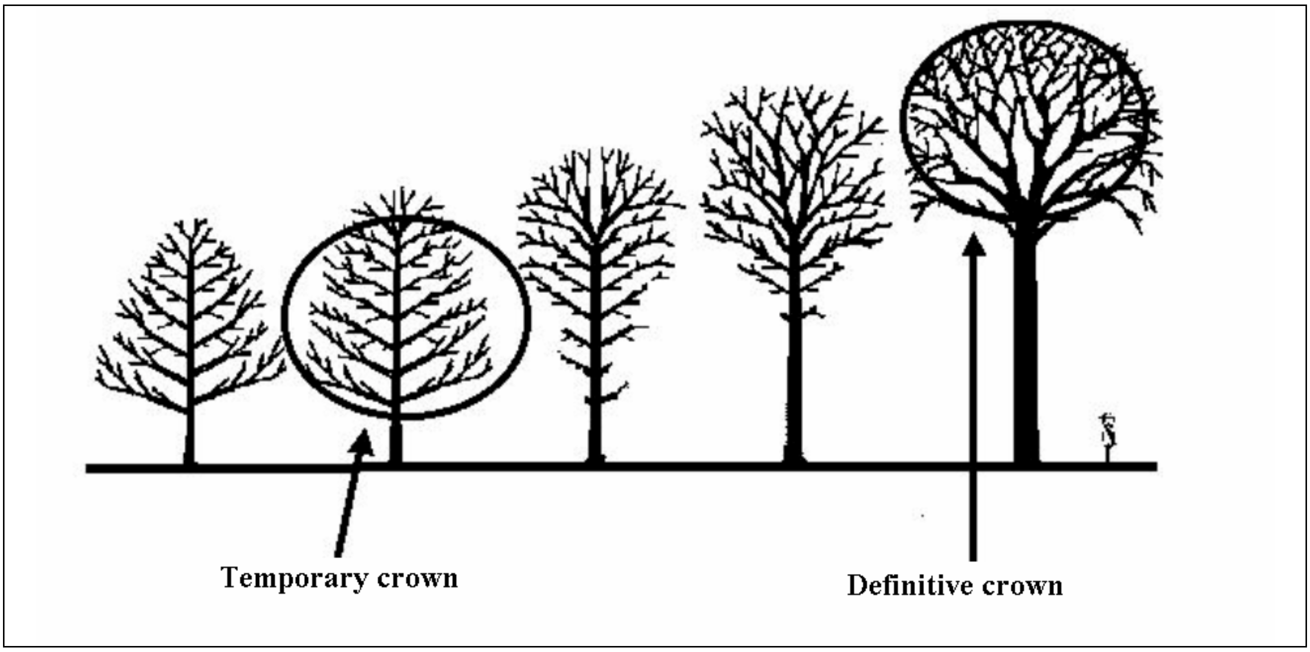
It is interesting to ask (and we will, further ahead) if in such cases we can continue to call them "lateral branches".

Later on, starting from phase 4, no more lateral branches will be formed (the tree grows from the top, forming the adult crown with successive crotches), and the existing lateral branches, formed in the previous phases, will either weaken or die or stop acting as lateral branches.

1.4.5. Temporary crown and definitive crown.

As P. Raimbault explains it, the set of lateral branches formed in the earlier phases under a strong apical dominance, compose a temporary crown that will die and disappear in the following phases, leaving, in phase 7, a vertical trunk, without lateral branches.

In phases 6 and 7, the tree loses apical dominance, interrupting the single axis that opens first into one and then into successive crotches that, as indicated by P. Raimbault, form the definitive adult crown of the tree. Therefore, the formation of successive axes is evidence of the loss of apical dominance.



In the structure, the set of lateral branches isn't important, their presence only offers temporary support: they are the temporary part of the structure. Nevertheless, when there is abundant lateral illumination (isolated trees or trees on the edge of a mass), the lateral branches remain longer, even doing so indefinitely to become part of the definitive structure.

1.4.6. Shoots and water sprouts.

The tree grows and develops through the progressive ramification of its structure, either from the buds already present (following the order and logic of the previous ramifications), or from buds emerging spontaneously or as a response to some kind of alteration.

When not subject to the existing order and hierarchy, these emerging buds are called water sprouts and in the dictionnary they are defined as: "Shooting rod that sprouts on the main branches, the trunk, and even the roots of trees…".

Technically, a water sprout is a shoot defined as a delayed ramification (that emerges on wood more than one year old) that sprouts and grows independently from the hierarchy and the structural organization of the existing crown. It grows vertically and, in fact, reproduces the same structure development model as a seed sprout (phase 1, phase 2,...).

In addition to the known water sprouts, which are even capable of producing an entire new tree, there are partial shoots that don't grow vertically and vigorously, but that subordinate themselves to the existing structure and limit themselves to recomposing and renovating the existing crown.

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Chapter 2. THE ALTERED DEVELOPMENT: STRUCTURE OF THE URBAN TREE.

Given the difference in environment, development and treatment, it's important to make a distinction between trees from green areas and roadside trees.

Green areas can provide soil conditions, space and absence of pruning that allow, except for transplant shock, free development in which it is fairly easy to recognize Raimbault's model.

Conditions for roadside trees are quite different: scarce and poor quality soil, frequent alterations, aggressions, pruning, etc.

Therefore we will rarely find in the roadside tree clear examples of Raimbault's development model. Even so, the roadside tree, the pruned tree, constantly seeks to overcome, structurally and physiologically, the repeated traumas of pruning and, if left to develop freely, would finally end up manifesting the elements and logic of Raimbault's natural development.

Let's have a look at the conditionning factors of tree development in an urban environment.

2.1. Transplant shock.

2.1.1. The nursery plant.

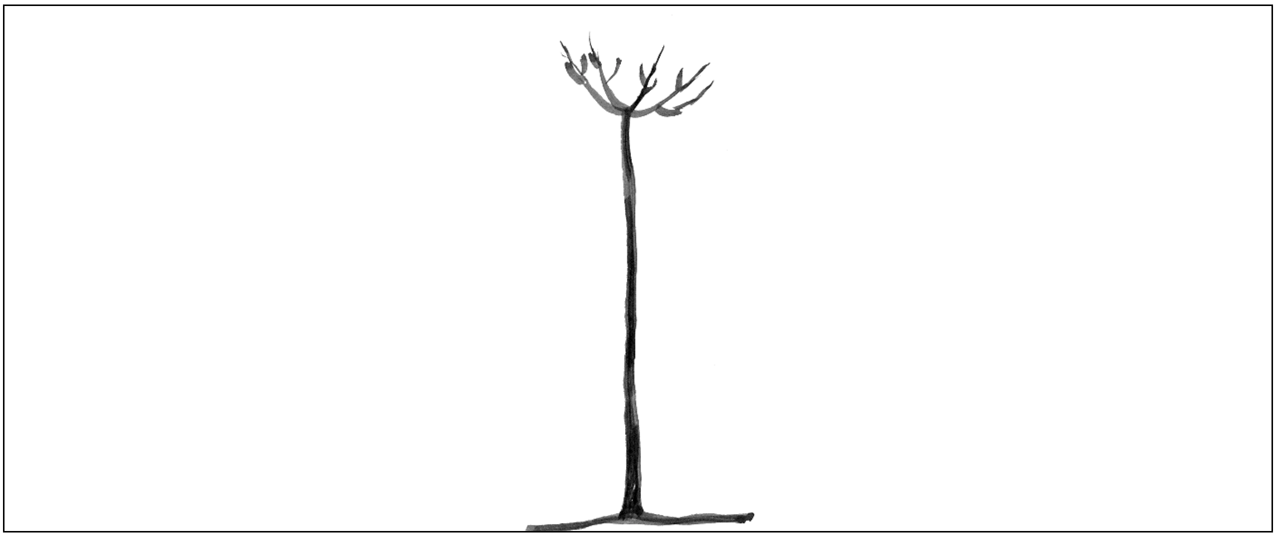
In the nursery, the plant is (or should be) in optimal culture conditions (light, soil, irrigation, etc.) and with all of the root's volume (exploration capacity, feeding, water, reserves).

After coming out of the nursery and being planted in urban soil, the plant usually finds itself:

- Deprived of a great part of its root system, which implies:
  - Absence or severe reduction of production of citokinines: there is no stimulation for developping buds on the crown.
  - Absence or severe reduction in its capacity to absorb water and nutrients.
  - Serious loss of reserves in the lost root.
- Topped, which implies:
  - Absence of apical dominance which organizes structural development.
  - Reduction of photosynthesizing surface.
  - Absence of auxins production in the crown: there is no stimulation for root development.
  - Serious loss of reserves in the wood that was eliminated from the crown.
- Therefore, strongly weakened, which implies:
  - Paralyzed development.
  - Absence of apical dominance.
  - Scarce production of photosynthesizing surface.
  - Scarce spatial separation between successive ramifications.
- In a soil much poorer than in the nursery:
  - Poor ventilation (from compacting and puddling).
  - Probably dry in summer and possibly puddled in winter.
  - More compact, sterile, etc.

2.1.2. Topping.

Traditionally, the plant has been topped when coming out of the nursery, either by eliminating the terminal guide or by reducing the crown if this was more complex. This was justified by the argument that we need to "balance the crown with the root", the root being very reduced. Other times it was a simple reduction of dimensions to make transportation easier.



Generally, for the nursery manager, it is cheaper to cultivate many plants per square meter, but this makes them grow in height, and an excedingly high plant cannot stand by itself after coming out and therefore it becomes necessary to reduce its height.

It is known that root sprouting is caused by the presence of auxins (like the ones contained in the products for rooting of cuttings), and that these auxins are formed in the crown buds. Topping means a reduction in the number of buds and therefore auxin production is also reduced and with it, the reduction of root sprouting.

At the moment, there is a tendency in nurseries to produce better formed plants (either without topping, or with a high crown) and with a strong, thick stem, but for this it is necessary to dedicate more space to each plant in the nursery (so that plants don't grow in height), which implies higher prices.

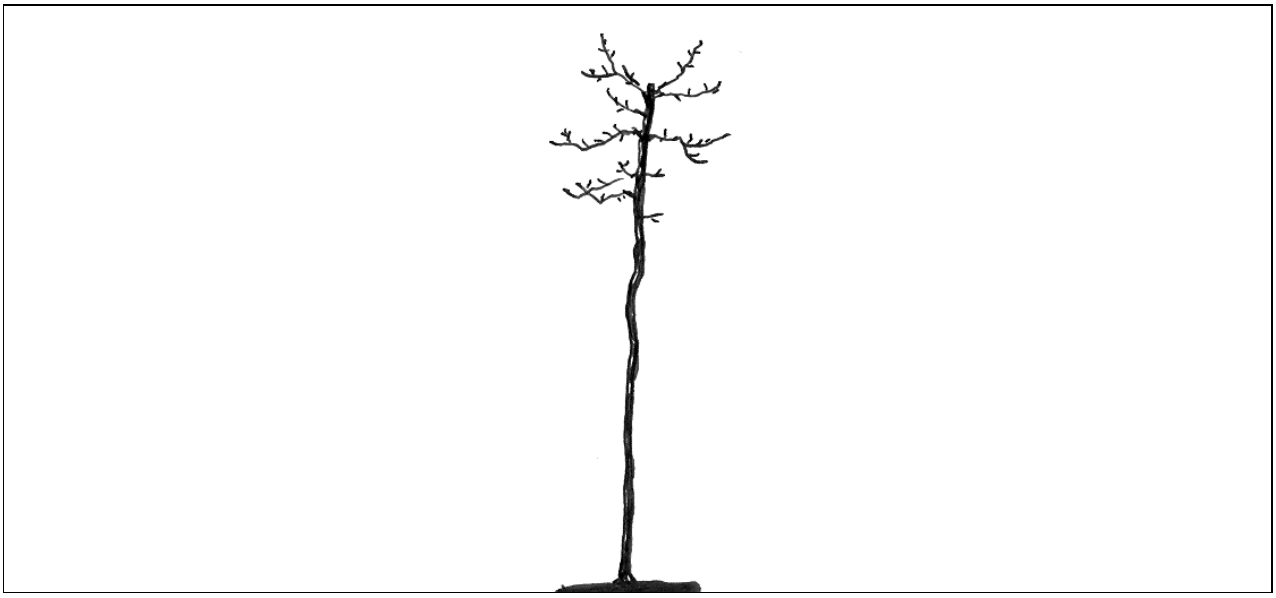
2.1.3. Incorrect planting.

Independently of the plant quality, planting itself can place the plant in an unsustainable situation if the root is put in dehydrating or asfixiating conditions. Deep planting is an adquired bad habit that collaborates (along with general bad quality of plants and incorrect handling of irrigation) to the failure of too many plantations.

Later on (see point 4.2) we shall comment on the correct conditions for proper planting.

2.1.4. Transplant shock.

The usual combination of topping, uprooting in the nursery (with loss of the major part of root mass), transportation, storage and planting (into conditions which are usually much tougher than the nursery's) cause transplant shock, a weakness hard to overcome (lack of vigor, scarce foliar sprouting, reduced photosynthesis and root sprouting, etc.). The lack of proper care after planting (absent or excessive irrigation, wounds caused by lawnmowers, etc.) contributes to the general weakening.



Many plants don't actually die, they just limit themselves to surviving for many years in that state.

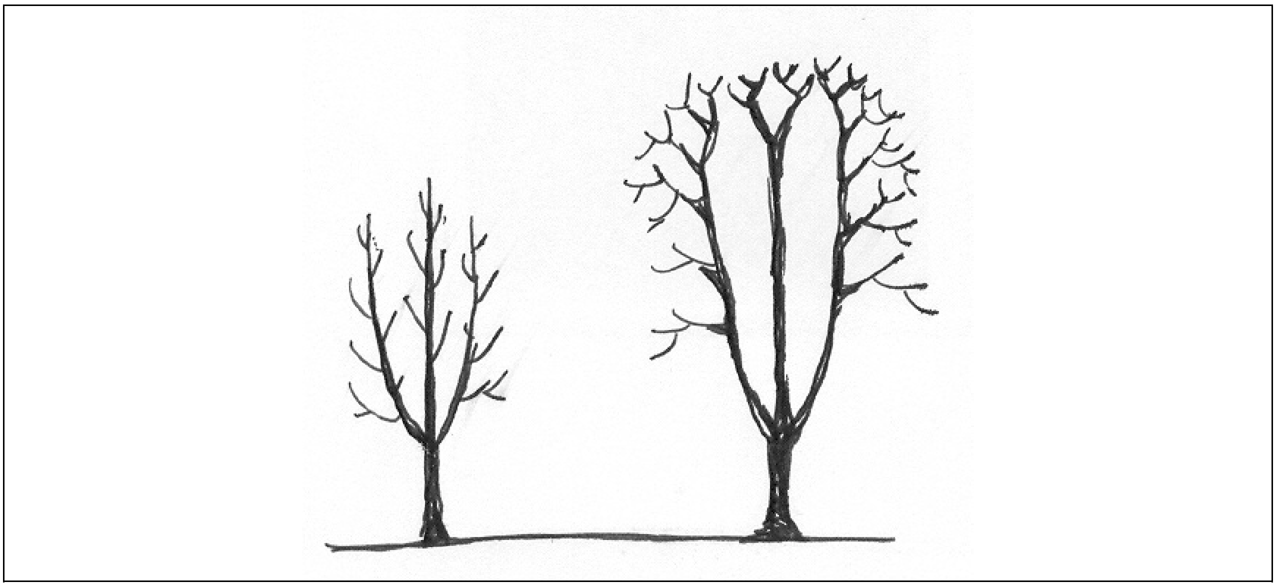
Even plants with an entire crown and complete axis can fall into this transplant shock if the quality and quantity of roots are low, if planting is incorrect, etc.

With transplant shock, the crown's structure development stops. If , previously, there was some type of hierarchy, it disappears. The sprouts, dispersed and disorganized, are short and with few leaves. The internodes, very short.

2.2. Urban tree structure in green areas.

The adult tree in green areas normally isn't subject to crown reduction pruning. Therefore, it's overall structure may coincide with Raimbault's model although it will usually show crowns and crotches, remains of the elimination of the lead and of a weakness crisis.

After planting, once the transplant shock has been overcome, vigor is recuperated and normal development occurs on a central axis or, more frequently, on a crotched axis with two or more vertical axes.



In species of great development, serious situations of structural weakness may occur due to the presence of bark in the inherited crotches.

From a bracket or a crown, a tree will have various vertical axes, each with its own clear apical dominance (depending on the species) and its own lateral branches: each vertical axis behaves like an independent tree, competing with all the other axes of the same tree.

To varying degrees and depending on the specific development, the vertical axis or axes will open up naturally through shoots and successive crotches, forming the definitive adult crown, according to Raimbault's model.

2.3. The roadside tree structure.

The roadside tree is, generally, subject to a more or less regular regime of crown reduction pruning.

Its structure, normally open into a crown, follows not to a normal structure development but the pruning and the consequent sproutings. Nevertheless, the laws of structure development still exist, and it is important to take them into consideration.

Generally, the adult roadside tree's structure is characterized by:

- Presence of a low crown, resulting from eliminating the lead and from transplant shock.
- A more or less fixed amount of main axes, defined by the pruning system.
- If, from then on, pruning is delayed and there is enough vigor, each axis will develop an apical dominance, with subordinated lateral branches. The axes compete with one another as if they were independent trees.
- If a height reduction is made on the vertical axes, one or more superior levels of crotches and secondary axes will appear, defined by the pruning system.
- Crown reductions usually cause the appearing of reiterative sprouts on the whole structure. The specific pruning regime will limit the temporary and spatial development of these sprouts.

If the relationship between the species and its allotted space is favorable, the pruning regime can be light or nonexistent and natural adult crowns can actually develop, formed by successive crotches. In these cases, it is posible to control the volume of the crowns with non-aggressive systems (reduction cut that removes a stem back to a lateral branch that remains, etc.).

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Chapter 3. OTHER CONSIDERATIONS AND CONSEQUENCES

3.1. STRUCTURAL STRENGTH AND DEFENCE AGAINST DECAY.

3.1.1. Ramifications. Defining lateral branches and crotches.

Alex Shigo makes a distinction between lateral branches, crotches and sprouts. He doesn't differenciate them by their origin and neither does he consider the possible existence of ramifications that are neither pure crotches nor pure lateral branches.

P. Raimbault differenciates by origin ("such circumstance or moment of the tree produces such type of ramification"), as we have already seen, and in addition he predicts its future evolution ("a lateral branch belongs to the temporary crown, and it is destined to disappear", etc.).

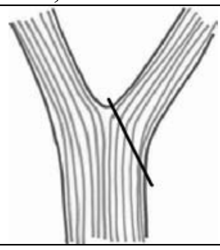
More specifically, Raimbault differenciates the juvenile phases, defined by the presence of an apical dominance and a series of dominated lateral branches, and phases of crown development, where a progression of reiterative developments is given.

Raimbault's simplified definition is more complex and profound than Shigo's and doesn't contradict Shigo's proposal of the presence of defence against decay at the base of lateral branches.

3.1.2. ¿Is there a barrier against decay at the base of ramifications?

One of the most widespread and used contributions of A. Shigo is his definition of the "defence against decay at the base of the lateral branch" ("branch protection zone"), which is the foundation of his proposal of the "correct cut of the lateral branch". With it we have a guarantee that the correct cut of the lateral branch will not produce decay.

Shigo has also talked about crotches, and clearly states that there is no defence against decay at the base of the scaffold branches. That is why there is no "sure cut" of a scaffold branch; what needs to be attempted is their early removal, or the least harmful cut possible.



Shigo describes how the annual thickening of the xylem (the "wood ring") is formed every year, first in the lateral branches and then in the trunks, therefore producing first a slight invasion of the lateral branch's xylema in the trunk area, and a few weeks later, as the trunk thickens, a slight invasion of the trunk's xylema at the base of the branch. This produces a small annual overlapping at the base of the branch which causes the typical widening of the base of the branches and the good anchorage of the lateral branches in the trunk.

This overlapping which started when the branch was thin, would also be the physical structure on which the famous "defence against decay at the base of the lateral branch" is based .

This overlapping doesn't take place in the crotch branches since they are of the same caliber and thicken every year simultaneously: the crotches therefore have a poor anchorage and have no "defence against decay" at their base.

But for Raimbault, lateral branches are only the sprouts that emerge under a strong apical dominance, and the set of lateral branches composes a temporary crown that will disappear and die as the adult structure develops above.

The death of the temporary crown, announced by Raimbault, "needs" the defence at the base of lateral branches described by Shigo, and will only occur in the temporary branches destined to disappear.

At the same time, Raimbault's definition of what is and what isn't a lateral branch within a tree structure gives us information about where we can find Shigo's barrier at the base and where not.

The crotches that appear successively in natural development when the apical dominance disappears will compose the permanent adult structure. They are the definitive structure, so they don't need decay barriers at their base. And Shigo states that indeed they don't have any.

In the altered development typical of the urban environment, the whole structure can be formed by crotches and shoots.

In such cases there wouldn't be authentic dominated lateral branches and therefore, no barriers against decay.

3.1.3. Structural strength of lateral branches, crotches and sprouts.

The fiber overlapping at the base of the lateral branch produces a solid structure. Only the undesirable including of bark between the lateral branch and the trunk can produce a structurally weak spot but, generally, this only happens in varieties or artificially columnars or "Fastigiata" form.

The crotches are weak structures, even without included bark, for there is no overlapping and some fibers may go from one branch of the crotch to another given that both branches' fibers are directed downwards, in parallel.

Nevertheless, in natural development, the crotches don't need to be structurally strong and as a matter of fact, fractures rarely occur there. This is because, as we have seen, crotches don't appear in the structure until phase 6 when the central axis opens up in successive crotches. Each of these successive crotches is strong enough, given that:

- There are no cases of included bark because vigor has slowed down (there are many crotches like this in the whole of the crown, and the growth expectancy on each crotch is low) and because later thickening is expected to be low.
- There are no excessive efforts:
  - Because the sail supporting each branch of the crotch is very small (a small percentage of the whole crown).
  - Because the lever arm (the distance from the center of the wind's push up to the branch) is short.

Nevertheless, where development is altered, crotches can appear in the lower part of the structure and these crotches are weak since:

- They tend to form included bark through progressive thickening.
- Structural consolidation is compromised (see point 3.2).
- Excessive efforts can be produced:
  - Because the sail that supports each branch of the crotch is very large (up to 50% or more of the whole crown).
  - Because the lever arm (the distance from the center of the wind's push up to the branch) can be very large.

The frequent presence of structural reinforcements on both sides of the crotches with included crotches (reinforcements by structural consolidation, see 3.2), demonstrate the reality of the structural weakness.

Shoots are initially weak structures (basically, there are no fibers overlapping with the trunk), although this usually isn't a problem because the efforts that they support are also weak. But the big sprouts that are formed after removing the lead or topping in vigorous species with weak wood (poplars, etc) do get broken because the wood in which they are anchored can decompose.

3.2. STRUCTURAL CONSOLIDATION.

Claus Mattheck describes structural consolidation as the process whereby the vigorous tree detects the weak spots in its structure (spots where a localized accumulation of tension s is produced) and reacts by generating more wood, producing a structural reinforcement in the exact place and correct measure either in the crown, the trunk or the root.

The structure's own growth, weight increase, the increase of the wind push, structural weaknesses produced by wounds, defects, decay..., all unleash regular, punctual processes of structural consolidation.

Structural consolidation appears as an essential mechanism that, from a determined structure whether natural or not, provides necessary solidity.

But there will be no structural consolidation if:

- Although there are defects or structural weaknesses, the tree doesn't perceive them (for example, if the tree is staked).
- There is no vigor, if the tree is weak.
- There are physical impediments that stop thickening and reinforcement (tight crotches, small tree wells, etc.).

3.3. NEGATIVE CONSEQUENCES OF PRUNING.

Costs aside, we would like to carry out as intensive and frequent pruning as we wish, but normally some undesirable consequences appear:

- Massive sprouting as a reaction to pruning
- Disorganization
- Weakening
- Infections
- Decay, structural ruin

3.3.1. Massive sprouting as a reaction to pruning.

The crown reduction in a vigorous tree causes the appearing of emergency sprouts (shoots) and the more extensive the reduction, the hardier they will be as they seek to reproduce the original volume of the crown.

These shoots can appear in the cut area as well as in dispersed spots on the structure.

Structurally, they are more juvenile forms than the eliminated parts and in a way they rejuvenate the structure but never revitalize it because the entire tree is weakened (reduction of reserves, of photosynthesis, etc.).

These massive shoots can be undesirable (if we are seeking a clean structure) or desirable (if we are going to carryout crown reduction prunings by general removal of sprouts, see 5.4.1.1.).

3.3.2. Disorganization.

We define disorganization as the undesirable alteration, whether temporary or definitive, of the natural structure development process defined by Raimbault.

Natural development orders the sprouts in space and time in function of the vigor and the age of the tree, spontaneously producing a correct adult structure.

Reduction prunings alter natural development, producing:

- Spatial disorder: crotches appear in the trunk, the natural spacing between ramifications is altered, branches accumulate in determined spots ("knot" or "node"), etc.
- Timing disorder: structural elements of mature age appear (crotches) in the young structure, juvenile structural elements (vertical axes) in the adult structure, etc.

Crown reduction pruning systems produce permanently altered tree structures in which the pruning regime prevents the evolution of a self-organized, hierarchical structure.

3.3.3. Weakening.

Weakening is a situation of insufficient production and energy reserve to attend the different physiological demands.

In an urban surrounding that is generally limiting rather than optimal for tree development, an excessive pruning regime can easily lead to more or less chronic and progressive weakening situations.

There are prioritary physiological demands that the tree can't neglect without dying: basic metabolism, annual production of xylem, phloem, leaves, absorbent roots, etc. But weakening will cause the tree to neglect secondary physiological demands, which are vital in the long term:

- Structural consolidation (in the crown, trunk and anchoring system).
- Cambial covering of wounds and cuts.
- Compartimentation of active decays.
- Defence against pathogens.

Recurrent pruning limits the progressive increase of foliar production and, with in turn, the progressive increase in photosynthetic activity; in short, it makes things difficult and can impede energetic recuperation.

3.3.4. Infections.

Pruning cuts, like any wound, imply openings in the bark and possible access areas for diverse pathogens:

- Structural decays. Decay is the invasion of the structural wood of the tree (crown, trunk and root) by xilofagus fungi, with varying degrees of structural weakening and risk of derived accidents. Alex Shigo demonstrated the process of decay in live trees (which is very different from the process in dead wood) and defined the decay compartmentalization system (CODIT), which only operates in vigourous specimens.
- Infections of all kind.

Although Shigo demonstrated that the correct cut at the base of lateral branches doesn't cause decay because of the existence in this spot of a barrier against fungi, we are seeing in this text how adult trees in general, and roadside trees that are subject to periodic prunings, practically don't develop lateral branches, their structure being composed of crotches and shoots that are not lateral branches.

The gravity of the cuts as a factor which unleash decay depends on the species, the type of branch, the diametre of the cuts and the tree's vitality.

3.3.5. Structural ruin.

As we have seen, the loss of vigor reduces or impides a series of vital processes, like structural consolidation and compartmentalization of decay, which cause other processes, slower or faster, of structural ruin. The weak tree doesn't react with vigourous sprouting in the cutting points, it actually presents cambial regression, dying, backwards or laterally, the cut branch or topped trunk.

In many species, the bark is very resistent to decay, staying in place even though the cambium dies and the wood degenerates. Under the sight of solid and continuous bark may lie a dead and more or less ruined structure.

…………………………………….

Chapter 4. TREE PLANT AND PLANTING.

It is necessary, in a study about structural development, to speak about planting, given its influence on vigor and on posterior structural development.

The objective of planting is to achieve a healthy and vital plant that will start developing as soon as possible. This requires:

- a good quality tree plant,
- the correct process of plant handling and planting, and
- adequate care in post-planting.

4.1. Plant quality.

Given that it is impossible to grow the urban plant by sowing, it is necessary to produce the plant in a nursery and then transplant it, when the time comes, to its permanent spot. This brings with it a series of problems and contradictions which are difficult to solve:

- Tradicionally, plants with bare roots or balled and burlapped have been used, leaving about 90% or more of the root at the nursery.
- The need to keep more of the root led to using plants grown in containers but over time, the appearance of serious spiraling or strangling problems, restrained the initial enthusiasm.
- The burlapped plant (expensive and unpractical for its own weight) helps to maintain the little root it contains in a good state, but hides the possible scarcity of roots and their possible defects.
- The hope of obtaining more fine root led to the idea of multiplying reinsertions of the roots, but Raimbault warns that after many reinsertions, the plant loses the capacity to reelaborate a hierarchized taproot root system (main roots, secondary, etc.) and tends towards a diffused root system (set of roots of the same category), which may affect adult anchorage and selfsufficiency in providing water.
- The need for speed and spectacularity of plantations leads to the use of bigger plants, but the bigger plant comes with a smaller proportion of roots than the small one, and the later overall development is therefore compromised.

None of the root types, in itself, guarantees a correct quality.

The objective is to assure a strong rooting and development. This requires the most complete and wide crown as possible (photosynthetic surface) and the maximum amount of fine roots.

The optimal plant for roadside would be:

- central axis and specifically formed crown (structure and height of the crown) in the nursery for the location to which it is intentioned,
- crown not trimmed before leaving the nursery, numerous buds capable of providing sufficient auxins to the root,
- medium size (16/18),
- adequate proportion of height and diameter, shooting mustn't be excessive,
- reinserted root 1 or 2 years before uprooting,
- bare roots, good enough in most cases (except conifers and certain species),
- absence of crotches in the trunk,
- absence of wounds in the trunk.

The quality and quantity of roots is fundamentally important although not always taken into consideration. The more inadequate the conditions awaiting the plant after planting, the better the plant should be, in terms of quantity and quality, particularly the roots.

After planting, a race against time starts between the dehydration of the plant at the expense of reserves present in the wood (which increase with foliar sprouting) and the production of new fibrous roots, which occurs later.

Water absorption will only be possible when an significant amount of new absorbant fine roots is formed, which requires both time and effort for the plant, even more so when the root that reaches the planting site is thick and scarce. On the other hand, the formation of fibrous roots requires a very precise proportion of water and air in the ground, which is not always available.

The time and effort required is reduced if the plant has abundant fibrous roots, which is only possible with a reinsertion made 1 or 2 years before uprooting.

It is much better to pay for a good reinsertion than for a bad root ball.

The plant that comes in a container has preferably been developed in soil and passed to a container 1 or 2 years (not more) before its sale.

A bad quality plant is, for example:

- A plant with a double trunk, crotched. This is unacceptable.
- A plant that has developed vigorously more than 2 years in a container: it will definitely have spiraled roots, formed into a ball.
- A plant with insufficient quantity and quality of roots.
- A plant that was topped during the same winter as its sale.
- A plant with roots left exposed after uprooting.

Although some of these conditions may be verified visually, the quantity and quality of the roots within a root ball or container is difficult to check. There are two possibilities:

- the destructive inspection of some plants in the nursery (breaking the root ball or uncovering it with a water spurt), possible (and very recomendable) in contracts implying many plants, and
- evaluation of the cut roots that stick out of the root balls:
  - few cuts of thick diameter indicate that there were no reinsertions, that the thick roots were cut off during uprooting, and that almost the entire root was left in the nursery.
  - many cuts of small diameter indicate that there were reinsertions and that the root ball contains a good amount of fibrous roots.

Because of this, contrary to the usual recommendations from nurseries to leave the protective materials around root balls (metallic nets, burlaps, etc.), we recommend removing everything, not only to avoid useless barriers, but to see and evaluate the present roots.

One of the purposes of the root ball and the container is to keep the roots humid and alive, but this isn't achieved by magic. In the same way that bare roots need special care during transportation and storage, containers and root balls need them as well (avoiding frosts, dehydration, etc.). A root ball or a container is difficult to rehydrate, whether before or after planting. In sandy soil it is practically impossible to rehydrate a root ball with post-plantation irrigation.

4.2. Tree plant handling and planting.

Apart from injuries and breakages, the main dangers for plants, between their exit from the nursery and the moment of planting, are the drying or freezing of their roots. Plants must be transported and stored in such a manner that they are protected from frosts, and the humidity of their roots is maintained (whether they are bare, in a container or root ball), watering them if necessary.

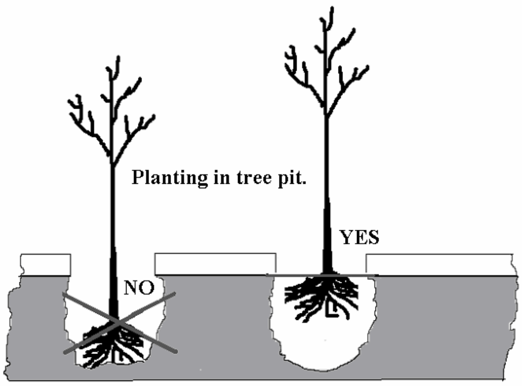
No crown reduction must be carried out, not even with the intention of "compensating crown and root". If the root is scarce, that means we have a bad plant, but there is no need to make it worse by reducing the crown for no reason. If the shooting of the trunk is such that it doesn't stand vertically, that means that the plant is unacceptable and shouldn't have been bought in the first place.

Planting a tree that doesn't have a minimum quality is a useless waste of time and money. It's better to just discard it.

Due to the general poor quality of urban soils, an effort has to be made to place the root in the most favorable conditions.

A practically generalized limitation in urban soils is aeration. Planting must provide a renewal or at least ventilate the largest volume of soil as possible. Especially in tree pit, if the soil is very poor and compact, it is necessary to renovate the largest volume of soil as possible.

Given that ventilation decreases quickly with depth, when planting it is important to place the root as much as possible at the surface, as it was in the nursery soil. When planting in tree pit, the lower part of the cement slab will be considered the soil surface. Planting deep, especially in clay soil, will suffocate the root and it will die.



When planting in free soil (green area, large tree pit, etc.), we should do so in a wide hole, not particularly deep (100 x 100 x 60 cms. for a medium development species, a bit more for a bigger species), swaping the extracted soil for a good vegetal soil, and placing the root neck at the very surface of the soil, not deeper.

It makes no sense to try solving a problem with another one: if the shallow planting implies a dehydration risk, the solution is not to plant deeper but to water frequently. If the shallow planting doesn't hold the plant solidly and there is a risk of the plant falling, the solution is not to plant deeper but to stake it.

When planting in winter, it may not be necessary to water immediately, but local conditions should be considered.

It is very recomendable to use some type of mulch on the surface, about 10 cm thick. In green areas, the mulch will not only contribute to soil ventilation but also will prevent the growth of grass, and consequently removes the need for lawnmowers to come close to the trunk, risking wounds.

It is not recomendable to fertilize at the moment of planting.

4.3. Planting season.

Tree planting should take place in the early part of winter rest and better sooner rather than later.

In theory, the containerized plant conserves all or most of its root and so, in theory, it could be planted at any time of the year. Nevertheless, irrigation needs are critical when planting is made with all the leaves, and it is important to supply them without excess or deficiency. This is easy in the nursery, but complicated after planting.

Even with containerized plants, we recommend planting them in the winter.

4.4. Taking care after planting.

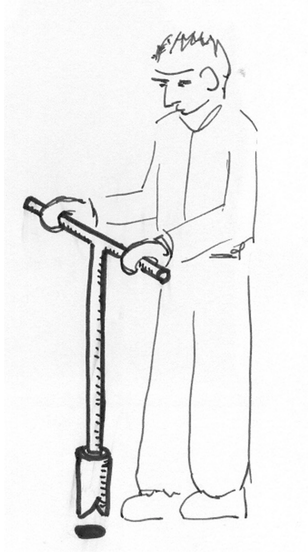
4.4.1. Irrigation.

The main worry after planting should be the correct grade of soil moisture. The plant's roots are greatly reduced as is its capacity to absorb water, so water should always be available although never in excess.

Excess water in soil (especially in clay or compact soils) saturates the pores, expulses the air and chokes the root. Puddles forming on the ground in spring or summer, together with high temperatures, choke the root through a total absence of oxygen.

Given the scarcity of the root, its weak development and expansion into the soil and the recommendation to plant in the surface, for the two first years it is preferable to water very frequently than to allow long intervals of time between waterings.

In each type of soil, in each city, the correct balance between moisture and ventilation is achievable with a different irrigation frequency. The water need can only be evaluated by taking samples of the soil with a soil sampler, in a sufficient number of trees (one out of every 20 for example).



Deciding the water need by looking at the state of the leaves can lead to confusion because we may be dealing with a drowned root through lack of ventilation (sometimes caused by puddling on the ground), for the symptoms are very similar.

4.4.2. Protecting the trunk from the sun.

We have been witnessing numerous cases of young plants with their trunk burnt laterally in the South-Southwest face, obviously from sunscald. It is recommended to protect the trunk during the first few years with some type of material that allows ventilation and reflects solar radiation without absorbing it (burlap fabric has been criticized).

4.4.3. Other cares.

When the root system becomes stronger and more voluminous, a remarkable growth will begin in the crown and the trunk will get thicker. At this point it is time to attend to possible strangling of the tree by the fastenings of the stakes and, later on, the removal of these, and structural pruning.

Chapter 5. STRUCTURAL MANAGEMENT OF THE URBAN TREE.

Structural management is the planning of the tree structure, in its specific location, from planting until maturity, and includes the formation of the young tree, correction of its defects, and direction of its structure towards a natural development (in those cases where there is enough space) or preparing of the structure to support a predetermined pruning model.

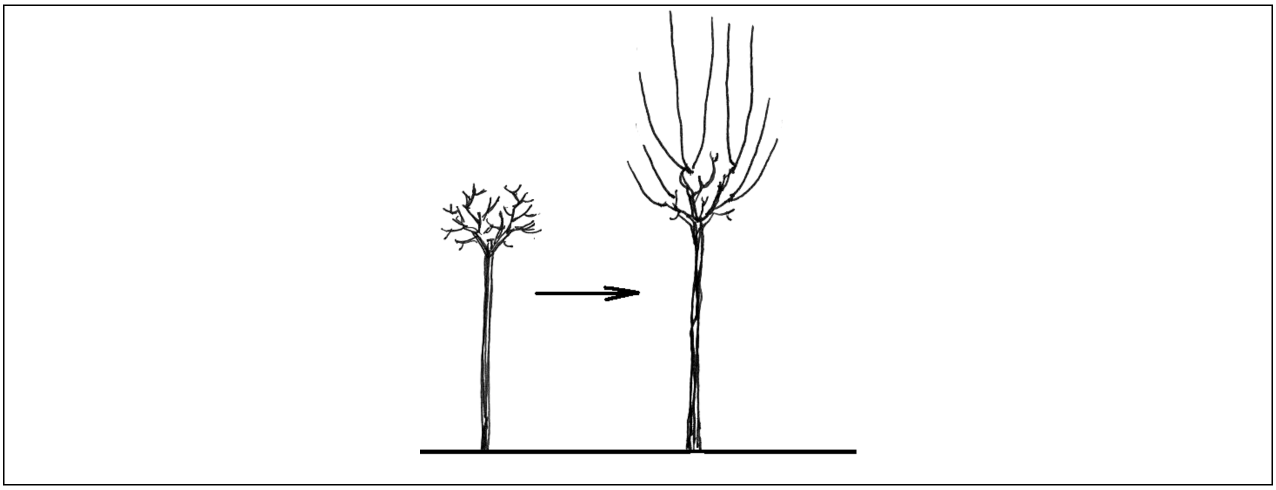
Obviously, the problems that will appear in the case of poor management get more serious when the development of a particular species is greater.

Structural management can transcend the individual tree and cover the overall management of a group of trees, including measures such as reducing tree density, etc.

All these actions only make sense within a structural management program that, together with other aspects, must be defined in the Management Plan of each tree area.

5.1. When to act on the young tree's structure.

While there is no vigourous development, the planted tree will only produce small buds with short internodes. The young plant needs a vigourous development to elevate its crown and organize its structure.



But this vigourous development won't happen until there is a sufficient root development. And at the same time, the root development needs a good crown development to provide it with energy and auxins.

No structural pruning action must be started until the plant shows vigorous development in the crown (significant elongations).

Any crown reduction made before the plant shows signs of vigorous development contributes to its weakened state and extends the transplant shock period.

Any attempt to structure the tree plant before it shows signs of vigorous development is doomed to fail because such measures will not produce ordered developments but small shoots and short internodes. Ordered developments only occur (and can only be directed) when the plant becomes vigorous.

If no action is taken, that moment when the plant starts to become vigorous is a moment when any present defect is aggravated and perpetuated, it becomes bigger. But this moment also allows us to take action, correcting these structural defects.

5.2. Correcting the structure of the young tree.

Correcting the structure aims to correct the young tree's defects that are caused by poor plant quality, accidents, transplant shock, etc.

Clearly, these measures for correcting structure must not be attempted before the plant reaches enters into vigorous development.

The most common malformations are:

- Crotches in the trunk.
- Crown formed by a concentration of branches with very short internodes ("knot" or "bundle").
- Excessively low crown: on roadside, we need a free space under the crown of 2,50 meters or more (4,50 m on the side of a traffic road).

5.2.1. Crotches in the trunk.

This is an unacceptable defect: this plant must not be bought nor planted. Correcting it is technically possible by eliminating one of the branches of the crotch; but it would only be reasonable to do so in the nursery (while the plant is fully vigourous) and makes no sense to do so during or after planting because it means eliminating half of the crown in a plant that is already weak.

5.2.2. Thinning the "knot" (defined in 3.3.2).

If we consider the crown height to be correct, we must consider this measure in order to thin the crown because if we don't, progressive thickening ends up with the branches pressing against each other with the consequent problems this brings (included bark, etc.).

Thinning will consist of eliminating branches, when the tree starts to be vigourous, until we obtain a crown with 3 or 4 well oriented and open branches (avoid branches oriented towards the center, towards facades, traffic roads, etc.). This might mean that we have to sacrifice a good part of the crown, but because we are acting on a vigourous plant (with a good root system development), the crown will recover quickly.

The shoots that appear at the level of the cuts in following years, should be removed when green (summer).

5.2.3. Crown raising and recovering the central axis.

If the height at which the crown was formed is considered to be excessively low, we will need to manipulate the central axis either to continue structural development or to open the axis into a higher canopy.

Manipulating the central axis mustn't be done before the plant starts to become vigourous, and consists of progressively removing all the existing branches except the best formed bud (which isn't necessarily the highest and most central). This is obviously a shock for the plant which, as in the previous case, loses a considerable part of its crown. But if root development really is good, the plant will easily recover from the crisis.

The shoots that appear at the level of the cuts in following years, should be removed when green (summer).

Plants used as rootstock frequently have many grafts at the same height. Normally, these crowns can't be elevated.

5.3. Structural formation of trees for open spaces without pruning program.

In open urban spaces (both green and paved areas), the general norm should be tree development according to natural structural models. The correct design and intelligent choice of species (maximum development, persistence or lapsing of leaves, size, shade density, color, etc.) allow a good range of creative options.

In certain spaces it may be convenient to control the free height below the crown with structural pruning as well as crown raising later.

On the other hand, controlling tree density in the long run (consciously planting more trees than desired and then selecting and removing the excess trees) will often be an indispensable measure for correct management (of the specific tree structure and the overall structure of the tree area and space), and equally should figure in the management plan.

5.3.1. Natural structural development.

Natural structural development depends on achieving two simultaneous and very related goals: obtaining a single central, dominating axis, and obtaining a very vigorous plant. When both requisites have been achieved, the development of the natural structure occurs spontaneously and no new measures are required, except in case of accidents.

The presence of possible structural defects in the young plant must be approached as indicated in 5.2.

5.3.2. Development in artificial and altered structure.

If artificial structures are desired for design reasons in open spaces, their formation is discussed in the following point.

5.4. Pruning models and structural formation of roadside trees.

Generally, urban space is restricted. This also applies to the space available for tree development, and particularly for roadside trees. Space restrictions mustn't be contemplated only for buildings but for all existing elements in each case: buildings, pedestrian and wheel traffic, traffic signs, landscape restrictions, etc.

Logically, design must contemplate a rational accomodation between the space available and the adult development of the species to be planted, and this should be the general rule.

On the other hand, roadside trees should have (as mentioned in 5.2) a single, vertical trunk without ramifications for the first 2,5 meters in pedestrian areas and 4,5 meters on roads for traffic.

5.4.1. Pruning models for reducing crown volume.

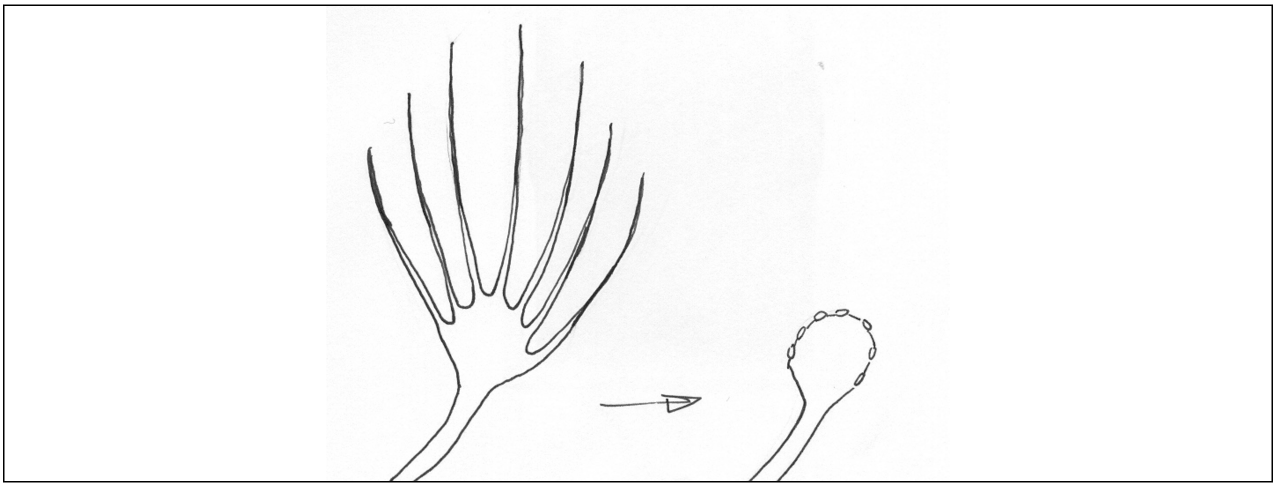
There are two basic models:

- General removal of sprouts (buds, shoots,...)
- Shortening branches and vertical axes.

5.4.1.1. General removal of sprouts.

This consists of removing all the sprouts that have emerged since the last pruning. These sprouts are buds or shoots, meaning that they are sprouts that have emerged on the wood that is more than one year old, as described in 1.3.6.

A strict model of this type is pollarding, with sprouts and cuts always being made in the same places every year or so. But less strict models can be used in which sprouts emerge and are removed in dispersed spots of the structure.



In any case, what is characteristic about this model is the existence of a permanent skeleton that is respected, from which abundant sprouts emerge and are completely removed every year or so.

From the perspective of structural development, the development is detained in an undetermined phase by pruning, there is no dominance nor hierarchy and each sprout is in phase 1.

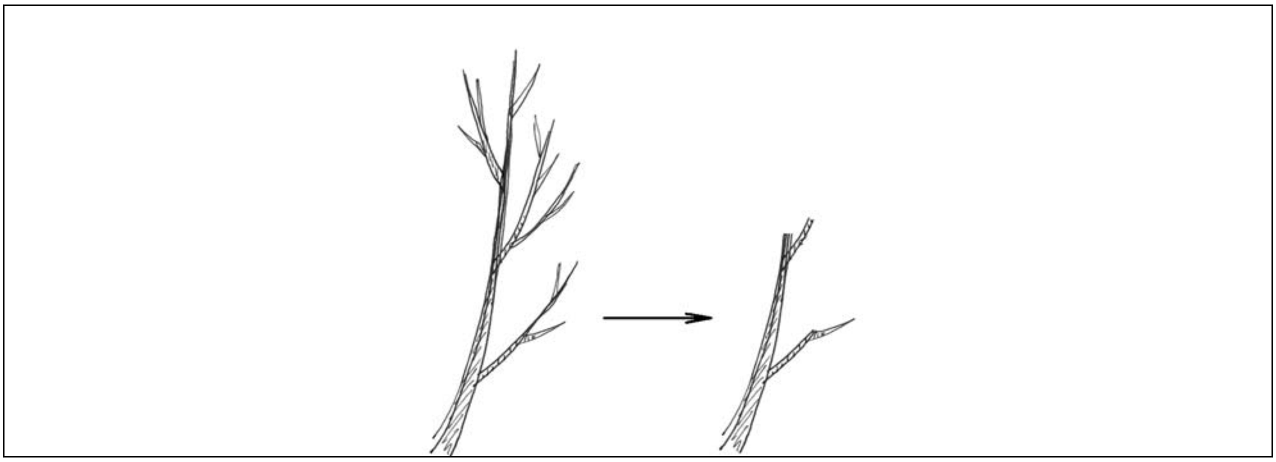
From the physiological perspective, these pruning actions are correct as they are executed with small cuts that the tree can close easily. In addition, the “heads” are places of regular energy accumulation, that can partly become fungicide and insecticide polyphenol, which protects the cuts.

Sprouts that emerge after this type of pruning are similar to those that were removed in type, importance and place. It is important to evaluate the tree’s vigor by the vigor of the sprouts, and the model can be sustainable as long as the tree doesn’t start to weaken.

5.4.1.2. Shortening of branches and vertical axes.

This consists in reducing the crown volume by shortening branches and vertical axes.

The intensity and importance of this measure can go from a light thinning (shortening the length of a branch by cutting to a lateral branch) to more serious pruning.



The reduction cuts are made on more or less thick branches. Depending on the species, the vigor or vitality of the specific tree, and on the intensity of the reduction that the tree receives, the tree will react (or not) with:

- Sprouts in the cuts and in the rest of the structure.
- Increasing growth in ramifications that weren’t removed (if there are any).

Exaggerated reactions indicate a drastic crown reduction and significant vitality. Moderate reactions or absence of reaction can indicate a mild reduction or a serious state of weakness.

The sprouts that emerge from this type of reduction are usually different and disorganized, which requires reorganization measures (sprout selection, clearing,...) before the next crown reduction.

If the reduction is significant, especially if the previous ones also were, vitality is jeopardized and derived consequences must be expected: development of structural decay, etc. It is difficult to evaluate the vitality that is left because excessive reductions, although they are a weakening factor, can produce strong emergency reactions.

If the reduction regime is very aggressive, in the end the tree only produces undistinguished sprouts, without organization or hierarchy of any kind.

It is difficult to predict or program the model. And although the young tree can endure it, it is difficult to sustain in the long run.

5.4.1.3. Mixed model: sprout removal plus shortening branches.

Frequently we can see a mixed model:

- In the first phase, all the lower structure of the tree is pruned by removing sprouts,
- In the second phase, many years later, the higher part of the crown is reduced and shortened.

The first phase “cleans” the lower part of the structure, undressing it, while the higher part of the crown continues to grow in height. The second phase radically reduces the tree height by shortening the vertical branches while, underneath, the structure develops sprouts as a consequence to the previous pruning phase.

This model allows aggressivity in the intensity of the pruning (which usually is very exhausting for the tree), but maintaining at all times the tree’s green crown, whether in the upper or in the lower part (which is esthetically bearable).

Given that the system itself erases all traces of its aggressivity (dry branches, cambial regresión, dropping of the crown, etc.) and that the tree will continue to sprout in some part as long as some life is left in it, this system can lead the tree to exhaustion and to structural ruin.

5.4.2. Stuctural formation of the roadside tree that will receive reduction pruning.

From the height of the trunk that needs to be free upwards, trees must receive a structural formation that matches with the crown reduction pruning that it will receive further along. Trees of a same alignment must receive a homogeneous treatment.

5.4.2.1. Structural formation for pruning by sprout removal.

As indicated, what is typical about this model is the existence of a fixed structure from which sprouts emerge and are pruned; a fixed structure that gets thicker as years go by.

The structural formation must achieve a structure, usually open in a canopy at an adequate height (although other models are also possible) maintaining the same number and disposition of arms in the set of trees, their arms being big enough to distribute the development of buds correctly in the available space.

Usually, all the heads are displayed in a single horizontal plane. In any case, the disposition must allow comfortable access to facilitate pruning work.

5.4.2.2. Stuctural formation for pruning by shortening branches.

In these cases, the structural formation must seek to open the structure of the crown, even at various levels, to reduce the vigor and growth of each of the axes.

There are no fixed rules or models and in any case the proportional relationship between the species and the available space mark the intensity and the rhythm of the reductions.

5.5. Pruning measures for specific causes.

5.5.1. Removing lower lateral branches: "skirting".

Essentially, crown raising doesn't seek a proper crown volume reduction but an anticipation of the spontaneous loss of lower lateral branches.

The urban tree, especially when roadside, requires a clean vertical trunk that occupies the minimum space possible in the transversal section of the road. The tree usually comes formed for that in the nursery but there are cases in which a greater free height is required below the crown. In green areas, lower lateral branches may or may not be acceptable.

In any case, crown raising consists of progressively removing the lower lateral branches, which can be done, at some point, without risk except in the case of an undesirable low canopy. In such a case, it is necessary to previously recover the central axis (see 5.1.2.3).

Frequently, the pruning technique of removing all lateral sprouts from the low structure of a tree is called crown raising; this isn't really crown raising but a reduction of the lower crown.

5.5.2. Reducing crown density.

Sometimes we talk about excessive crown density, excessive shade, "need for air"... It would be interesting to determine what is the problem and what is the objective.

If the specific foliar density is excessive, it doesn't make much sense to act every year to reduce the crown density; the correct solution is to change the species.

If the structure presents an excessive density of branches and sprouts, a structural formation is to be considered and the pruning program must be reviewed.

If the structure is correct, attempting to reduce the crown density doesn't make a lot of sense, at least not as a proposal and general pruning system.

Attempts to reduce the surface of wind push (in cases of breakage or falling risk) must be approached (as treated previously in 5.5.7) not by trying to reduce the density but by reducing the height of the crown.

5.5.3. Reducing interferences.

We call interferences those conflicts of competition for space between the tree and the other urban elements: buildings, pedestrian and wheel traffic, traffic signs, lights, etc.

An intelligent design (species, location, relative disposition of the planting spot and the rest of road elements...) can minimize or reduce conflicts to zero. A neglected design triggers an unending case history of conflicts without solutions.

In any case, respecting different elements is a priority, and we must achieve that the tree respects, without invading, the spaces reserved for the rest of the urban elements, whether by its own species-dependent development limits or by reduction pruning.

5.5.4. Natural loss of the temporary crown: "cleanse pruning".

As shown previously, the natural evolution of the tree structure is such that, in adult trees that develop freely, the whole juvenile crown ends up dying and falling to the ground, and that even in the higher, definitive crown, a large amount of temporary branches share the same destiny. Allowing such branches to fall, and especially from a great height, is unacceptable in an urban surrounding. So one of the most important jobs in trees and wooded areas which are developed consists of detecting and removing dry and weak branches.

This process doesn't happen in trees with crown reduction programs because the crown doesn't reach maturity. In these cases, the concept of crown cleaning refers more to removing broken branches, branches that are too close together, branches with wounds, etc.

Tradicionally, removing sprouts has been included in crown cleaning We have already indicated that sprouts can be formed for many reasons and so they must be interpreted and treated in a different way in each case.

5.5.5. Structural ageing.

As Raimbault indicated, the final tree phases inevitably lead to degeneration and structural ruin.

5.5.5.1. Structural ageing of the freely developing tree.

In the freely developing tree, this degeneration starts with the root system, reducing its funtionality, followed by the crown dropping, then the new formation of a disorganized interior crown and progressive loss of root anchorage. Internally, the wood experiences decay processes that weaken it.

All of this manifests as breakage and accidents, ever more serious when the weight and height are greater, and the importance or value of what lies beneath (people, objects…). Different species suffer this process more or less quickly.

Correct management must detect these problems and anticipate falls and breakages, whether through the necessary crown reductions (drastic, if necessary), or by removing the tree.

5.5.5.2. Structural ageing of the tree subject to crown reductions.

The tree that is subject to pruning reductions experiences a systematic removal of branches. This removal, that includes structural branches that might dry up, undraws the ageing process that nevertheless can be observed by structural imbalance (important parts of the crown are “missing”) and by absence of vigor.

Usually, repeated pruning ends up causing serious internal decay processes, which means structural weakening and risk of accidents.

The degeneration of root anchorage, also present, could be compensated by the fact that the volume and height of the crown (and consequently the wind push) are much more reduced than in the fully developping tree.

5.5.6. The structural reform of slanting or topped trees.

If the slanting or topping has been practiced on a vigorous tree and abundant sprouts are produced, its possible that the tree can recuperate its vigor within the next few years and deal properly with decay.

In those cases, conserving the tree is considerable through structural reform and a pruning plan.

In all of these cases, the safest solution is to form willow heads in the slanting or lopped spots, and then prune them every year. This way, the possible formation of voluminous crowns growing on weak spots can be avoided.

Only in the cases of young trees of species that respond well (*Platanus*, etc.) could we consider forming a complete structure, but even this could lack sense if a limit in available space was the reason that the topping was done.

5.5.7. Crown reductions forced by risk of breakage or timber.

The presence of damage or weak spots in the tree can mean a considerable risk of accident by breakage or fall.

In some cases, it is possible to reduce the risk by respecting the integrity of the crown (removing the target, artificial consolidation of the structure, etc.), but generally the most reasonable option is to try reducing the wind push on the crown.

From the works of L. Wessolly, we know that reducing the crown density isn't very effective; reducing the surface is what needs to be considered, and to be more precise, reducing the height of the crown, which reduces the surface and brings the crown closer to the ground where the wind's strength is always weaker.

There are methods to calculate the necessary reduction.

The structure doesn't always allow an adjusted reduction, and sometimes there is no other alternative than to remove the tree or to practice a certain degree topping. In any case, safety is a priority and the presence of a dangerous tree mustn't be allowed.

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Chapter 6. RELATIONSHIP BETWEEN PRUNING AND THE FITOSANITARY STATE.

Pruning is a permanent cause of weakening and of attacks by pathogens.

Reductions by sprout removal don't usually cause direct infections or decay (as explained in 5.4.1.1), but can lead the tree to become exhausted.

Shortening the branches and axes, especially for aggressive interventions, can also exhaust the tree, probably more than reductions by sprout removal, and also tend to cause structural decay and bacterial and other types of infections. The tree will try to defend itself from decay and infections, but it will expend its energy and reserves as well as loss of reserves on compartmentalization.

The weaknesses that are caused, as mentioned in 3.3.3, are to a certain degree interesting for the way they reduce the tree's growth rhythm, but can reduce the tree's capacities in a series of essential functions, also mentioned in 3.3.3: structural consolidation (in the crown, trunk and anchoring system), cambial covering of wounds and cuts, compartmentalization of active decay, defence against pathogens, etc.

Reducing the crown is necessary if the specific adult development is superior to the available space, but this means accepting the general presence of more or less weakened trees. The difference between the available space and the adult development of the species will give us a direct measure of how seriously the pruning will inevitably alter the tree physiologically and structurally.

This weakening can possibly be born by young and vigorous tree, but will definitely be serious in the adult, older tree. The specific species also plays an important role.

On another level, the presence of a certain amount and grade of pathologies shouldn't automatically lead to fitosanitary treatments (always questionable in an urban environment) but, first, to consider the health and vigor of the affected trees, their vital conditions and the pruning model to which they have been submited. And, finally, to the possible removal and replacement of the affected trees.

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Chapter 7. CONCLUSIONS.

In an urban environment, with trees that have been transplanted from a nursery into poor development conditions and serious spatial restrictions, pruning is an unreplacable tool for correcting, forming and structural management.

Nevertheless, and especially for roadside trees, using pruning to try to attend to and correct bad choices of design and species selection, plant quality in the nursery, planting, etc., leads to unsustainable situations in the long run.

Practical work experience demonstrates that the urban tree that is worn out by pruning, decay, plagues and disease rarely dies. This means that a good part of the roadside trees of our cities can survive in pitiful conditions, with a reduced functionality and becoming a real accident risk.

And the problem isn't only that a good part of current adult urban trees are dangerous, disfunctional, ugly and expensive to maintain, but that the younger trees can follow, inevitably, the same way because if the difference between the adult development of a species and the available space is serious, reduction pruning will need to be intensive, which is unsustainable in the long run.

All of this forces us to analyze what we are doing, what is happening, and why.

We are reaping the fruits and the experience of a time and a way of treating trees.

We come from a past filled with examples of generous tree areas, which might have been correct in their time, but that are affected by the modern city (traffic, frequent alterations of the urban ground, etc.) in a limiting way.

Road traffic requires more space than what was required 40 years ago, the paved surface is much stricter than before, soil conditions aren't the same.

The city has changed. And our knowledge has improved.

It's necessary to take part in the design of tree areas, taking into consideration the minimum needs of trees, incompatibilities, problems that will appear in the long run, etc.

Now, this participation must enable us to foresee the unsustainability of certain projects, and to bring solutions and practical proposals:

- ✓ adequate species for roadside,
- ✓ prediction of development (crown and root),
- ✓ models of compatibility between the space needed for root development and infrastructures,
- ✓ proposals of pavement that allow the soil to breathe,
- ✓ tree pit design, grilles and protection.
- ✓ etc.

On another level, nurseries usually ignore our headaches and play by their own rules. We need to establish protocols for plant production, especially for production that is destined to be planted roadside: formation, axis, crown presentation, size, reinsertions, root presentation…, and also assume that these requests will also have their cost.

Dedicating a higher budget to buying high quality plants, and hiring a technical inspector to select plants in the nursery are efforts that will be greatly compensated in following years.

Finally, it is necessary to elaborate management plans, and to follow them. Comprehensive management plans, considering the city as a whole, and partial management plans for districts, developmnets, specific streets and management unities.

Anything that can help to have a comprehesive vision of the process, to understand the past and plan the future, will be a useful advance for our daily work, for the functionality of urban trees and their sustainability.

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