



BIOMIMICRY RESEARCH INNOVATION CENTER

The
University
of Akron

Vers des fondations de bâtiments inspirées des racines d'arbres

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Biome+

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18 Juillet 2023

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Ceebios

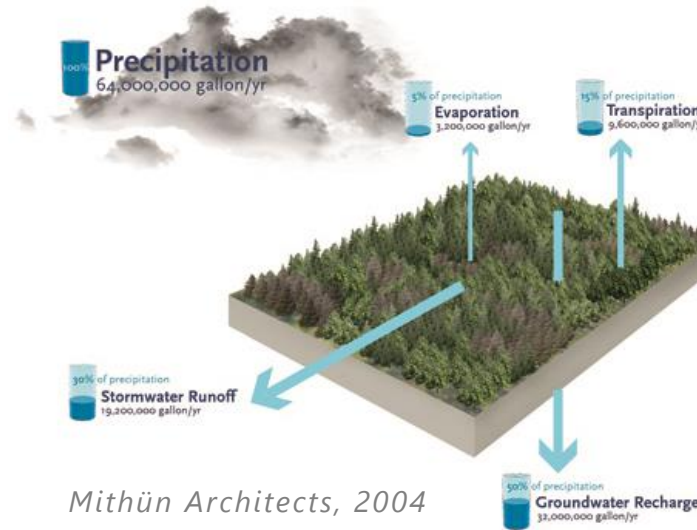


I - Contexte

I - Besoins de l'architecture de demain

› Renforcer les services écosystémiques

Lloyd Crossing Project, 2004, Mithün Architects and GreenWorks Landscape Architecture Consultants, Portland



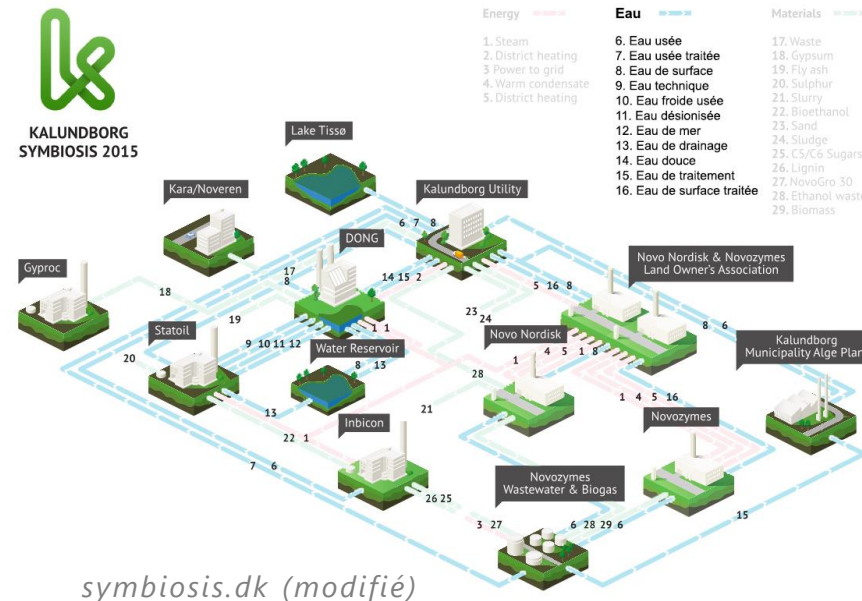
› Réduire la consommation de ressources

Kalundborg Symbiosis 2015

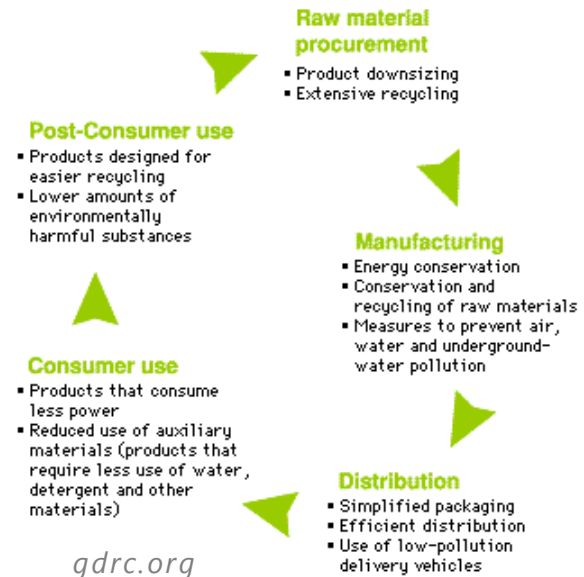
3 R: Reduce, Reuse, Recycle

Life Cycle Analysis

Biomimicry 3.8 Life Principles

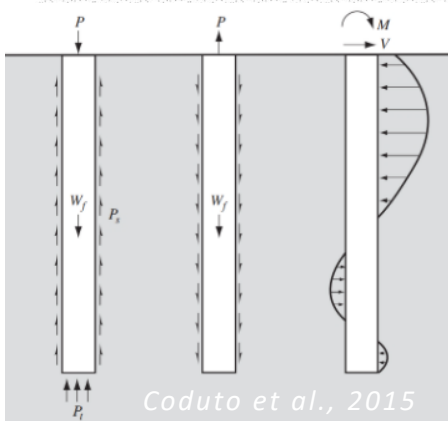
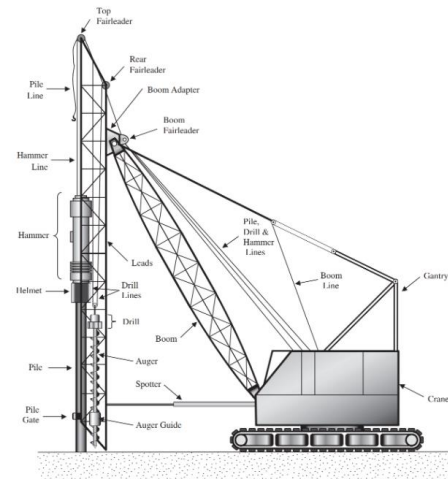


symbiosis.dk (modifié)



I - Cas d'étude: Fondations inspirées de racines d'arbre ?

Fondations traditionnelles



Fonctions des racines

Limite l'érosion des sols

Support structurel

Création d'habitats

Stockage: eau/nutriments

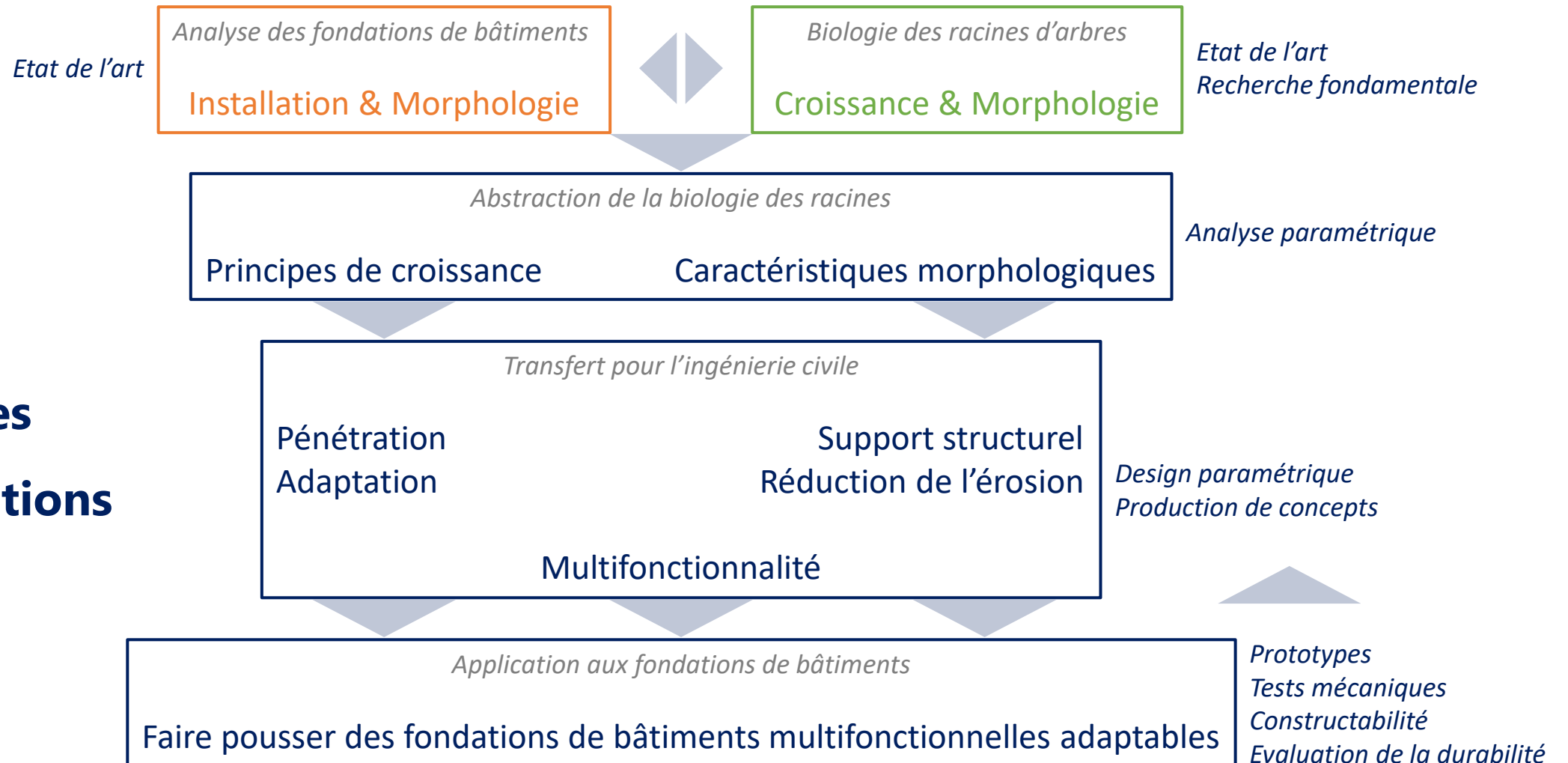
Absorption : eau/nutriments

Exploration et pénétration

I - Processus biomimétique

(simplifié, non-linéaire)

Des racines
aux fondations





II - Biomimétisme

en partant de la littérature scientifique

II - Processus biomimétique

Systèmes racinaires comme modèle biologique

- › Principes fondamentaux
- › Fonction, développement et adaptation
- › Biomécanique

Abstraction & Analogie

Application à des fondations de bâtiments

- › Problèmes des systèmes traditionnels
- › Solutions innovantes actuelles
- › Concepts inspirés des racines

Discussion & Conclusion

Root systems research for bioinspired resilient design - a concept framework for foundation and coastal engineering

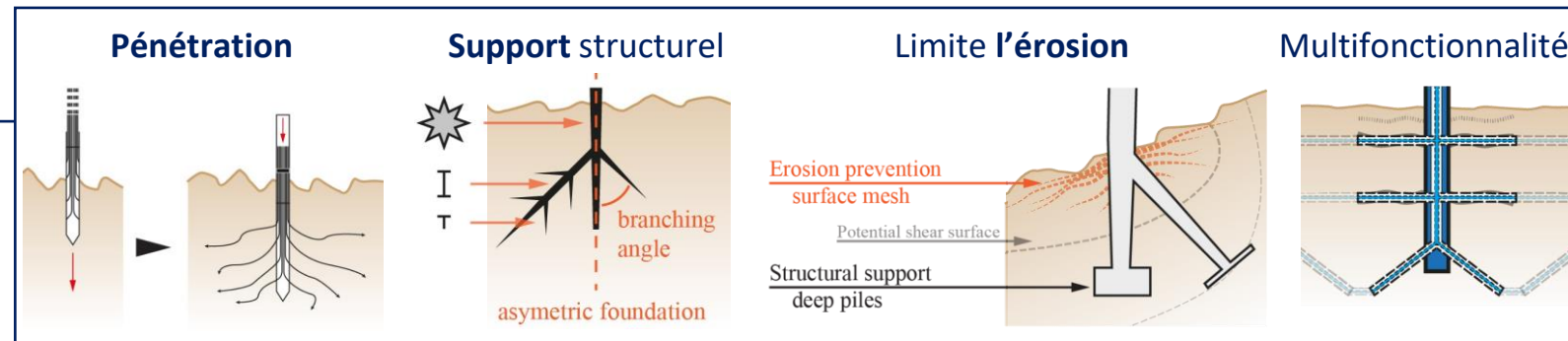
Elena Stachew¹, Thibaut Houette¹, Petra Gruber^{2*}

¹Biomimicry Research and Innovation Center BRIC, Department of Biology, The University of Akron, Akron, Ohio, USA

²Biomimicry Research and Innovation Center BRIC, Myers School of Art and Department of Biology, The University of Akron, Akron, Ohio, USA

| | Biological role models | Functions / Working principles | Problems / vulnerabilities |
|--------------------|--|---|--|
| Soil erosion | 1 Root/soil plate network behaving as one entity due to adhesion between soil particles and presence of root hairs (Coutts, 1983; Bailey et al., 2002) | Network of thread-like elements in contact with granular media to distribute load prevents movement of this media in response to tensile and shear forces | Soil erosion around building foundations, for example during heavy precipitation events, or exposed location on a steep slope/cliff (with or without precipitation) |
| | 2 Single root fan facing upstream deflects flow, additionally disrupts, partitions and slows the flow that passes through fan via drag, resulting in less scour within the structure (Svoboda and Russell, 2011) | Single flow deflection structure oriented in direction of predominant flow, composed of cylindrical elements with variable length, cross section, diameter / width, orientation and curvature arranged in a non-uniform porous branching pattern that disrupts flow through structure | High water velocity leading to erosion and poor habitat conditions |
| | 3 Position and orientation of several lightly placed rootwads in naturally occurring, stable log jams, including those constructed by beaver for habitat (Abbe et al., 1997; Abbe et al., 2003; Svoboda and Russell, 2011) | Large cylindrical elements with complex fractal-like endings facing the flow act as key anchoring and stabilizing elements of a single assembled porous yet stable structure of multiple elements | Coastal erosion and scour, specifically caused by wave action and reflection |
| | 4 Irregular distribution, configuration and porosity of roots and tree trunks in mangrove swamps resulting in flow obstruction / wave attenuation (Kazemi et al., 2017; Mazda et al., 1997) | Semi-rigid elements in a varied distribution of spacing and orientation in a continuous and connected system causing wave attenuation with reduced reflection, also increasing drag, which reduces downstream flow velocity | High velocities and wave action in nearshore area leading to coastal erosion, turbidity, poor habitat conditions due to high water flow and poor water quality, and inland flooding risk |
| Structural support | 5 Root/soil plate network and surface area to support structure (Svoboda and Russell, 2011) | Structural support through porous branching network | Low soil strength and poor soil conditions |
| | 6 Interweaving of roots and root granules between trees of same species connecting to mechanical support (Savill, 1983; Cremer et al., 1982; Loeble and Jones, 1996) | Continuous weaving of thread and stem like elements in a connected network in granular media | New engineering structures not connected to or benefiting from existing artificial structures already in place |
| | 7 Differentiated root morphology resulting from soil conditions due to wind and compression side and angle (Stokes et al., 2005; Nicolli et al., 2000) | Structural adaptation to soil conditions through differentiated elements on the ground surface | Engineering structures unable to change/adapt to changing environment |
| | 8 Differentiated root morphology for sloped terrain (Stokes et al., 2006; Reubens et al., 2007; Danjon et al., 2006; Liang et al., 2017) | Main deep sinker element providing anchoring with shallow thread-like elements retaining soil particles in a sloped terrain to stabilize structure and media | Engineering structures - such as foundations and coastal infrastructure - lacking specialized adaptation or design to sloped terrain |
| | 9 Adapted root distribution to chemical and mechanical soil conditions (Ennos, 2000) | Adaptation of structural morphology to changing environment | Fixed engineering structures unable to change/adapt to changing environment |
| | 10 Mangrove root morphology supporting and aerating the tree in both low-tide (roots surrounded by air) and high tide (roots surrounded by water) environments (Hogarth, 2015; Chira et al., 2013) | Flexible branching network able to transfer varying loads to granular media when surrounded by fluid of different densities | Structures built for one water level not effective outside of their designed range (e.g. seawall height unable to counter sea level rise) |
| | 11 Buttresses transferring loads from the trunk to the soilroot plate (Crook et al., 1997; Young et al., 1994) | Element connection shape optimized for stress reduction based on the tension triangles rule (Mattheck et al., 2005) | Stress concentrations in connections |
| | 12 Development of a "T" or "I" cross section in structural roots (Nicolli et al., 1996; Nicolli, 2009) | Adaptation of the element's cross sectional profile in response to specific loading conditions | Fixed cross section of elements, overdesigned to resist diverse loading conditions |
| | 13 Design of lateral roots and root hairs that physically attach to soil particles at the micro scale (Bailey et al., 2002) | Increase loading capacity of macro structures through skin frictional contact between granular media and network of thread-like elements by integrating highly textured micro surfaces | Foundations designed at macro scale not utilizing micro interactions between foundation and soil particles to increase loading capacity |
| | 14 Root mucilage enhancing bond strength between soil particles and roots to | Increase loading capacity of macro structures by attaching thread-like elements to granular media | Foundations not chemically connected to the soil particles at the micro scale for increased |

Stratégies des racines → Principes abstraits → Potentiel pour les fondations

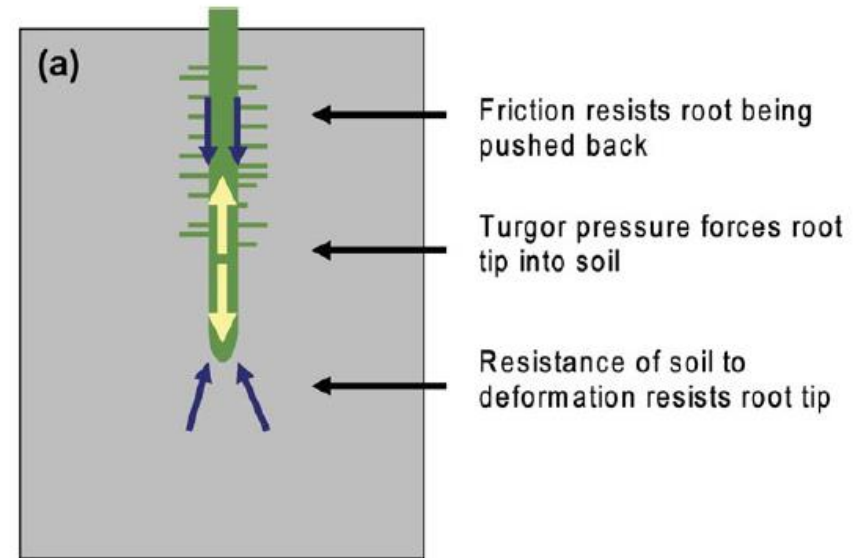


II - Stratégies d'intérêt

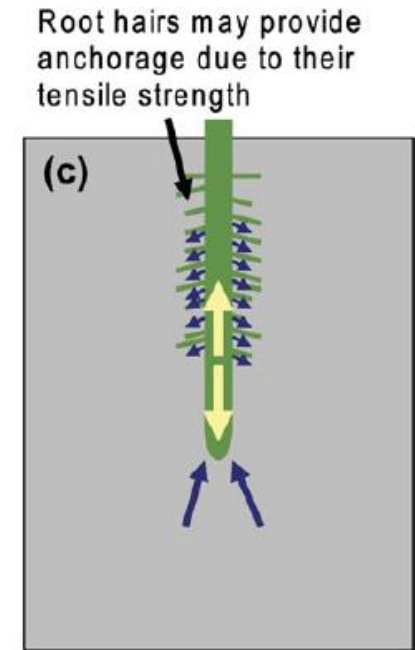
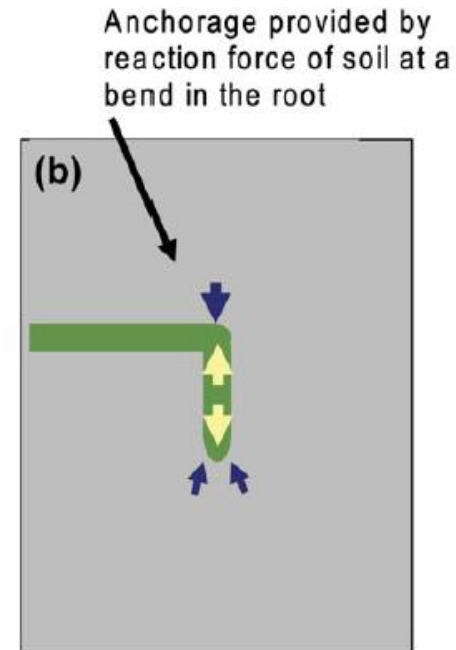
Pour les fondations
de bâtiments

1.

1. **Pénétration autonome des pointes**
2. **Système ramifié** augmentant la surface portante
3. **Friction** intégrée dans le design
4. **Multifonctionnalité** au sein d'une même anatomie
5. **Adaptation dynamique** à l'environnement
6. **Autoréparation** et décomposition programmée



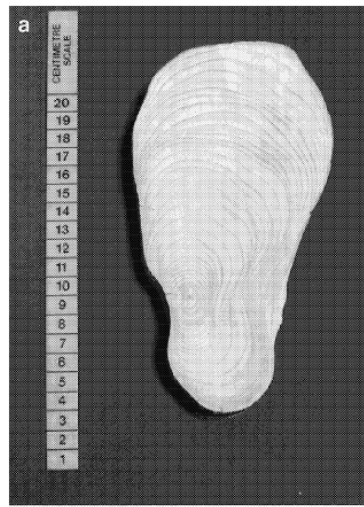
Bengough et al., 2011



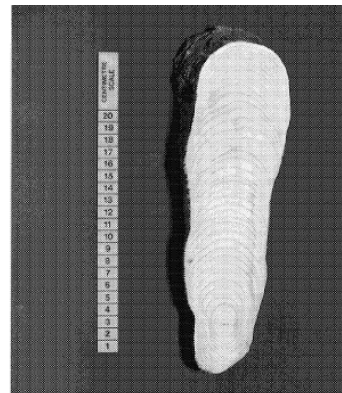
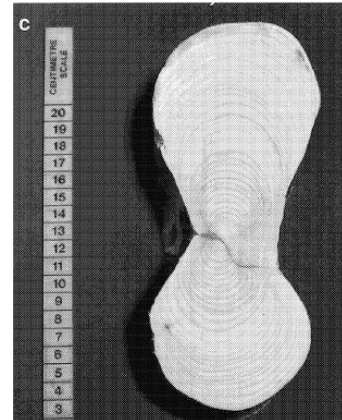
II - Stratégies d'intérêt

Pour les fondations
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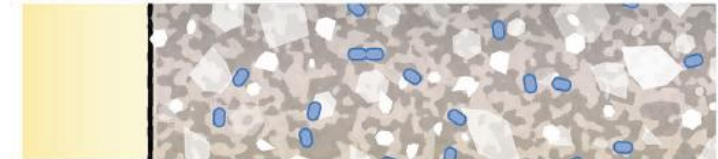
5.



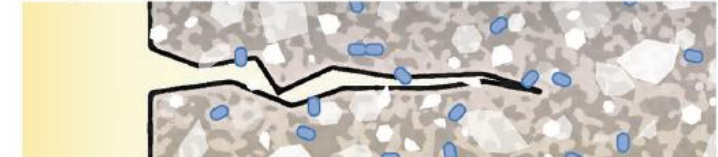
Nicoll & Ray, 1996

6.

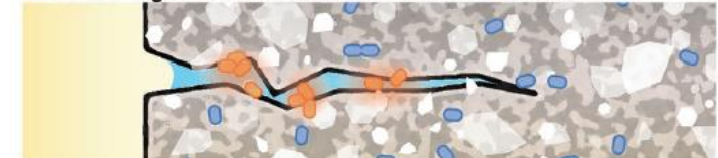
1. Bioconcrete contains dormant bacteria.



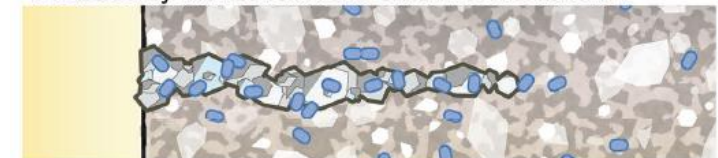
2. Upon damage, the interior is exposed to the environment.



3. Water ingress activates the dormant bacteria.



4. Bacterially induced mineralization fills the fracture.



Jonkers & Schlangen, 2007

II - Thématiques principales d'intérêt

Processus de croissance:

- Croissance par les pointes
- Circumnutations
- Formation d'embranchements

• Faciliter la **pénétration** dans le sol

Adaptation:

- Répartition de la matière dans le sol
- Racines à sections irrégulières
- Optimisation des embranchements

• Augmenter la capacité **structurelle**

Formation d'un bloc cohésif:

- Hiérarchie morphologique
- Entrelacement

• Réduire l'**érosion** des sols

Cycle des ressources:

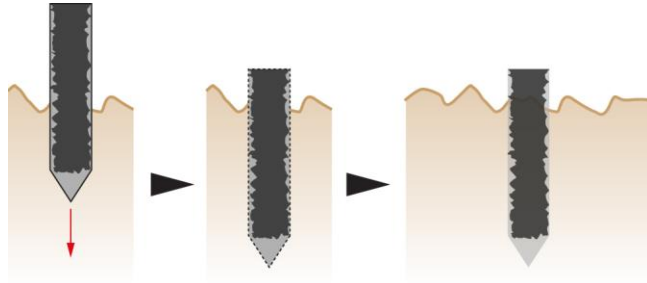
- Echange thermique
- Absorption, stockage et transport
- Matériaux composites
- Propriétés autocicatrisantes

• Intégrer la **multifonctionnalité**

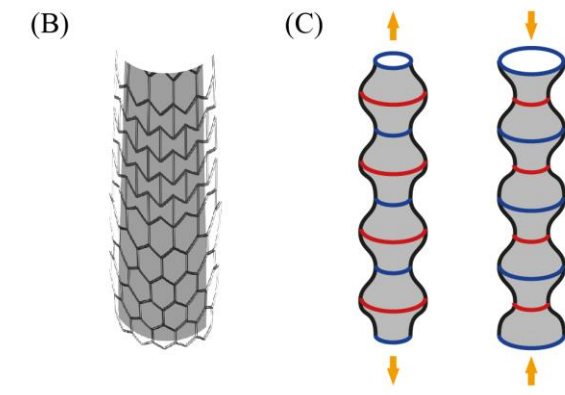
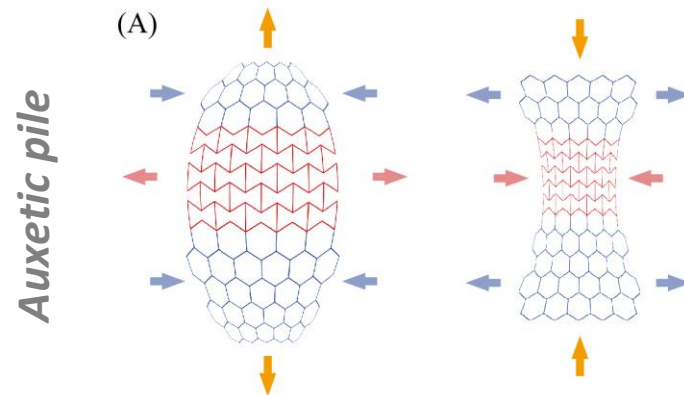
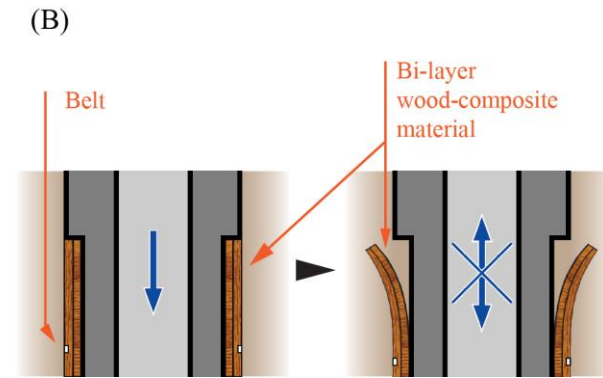
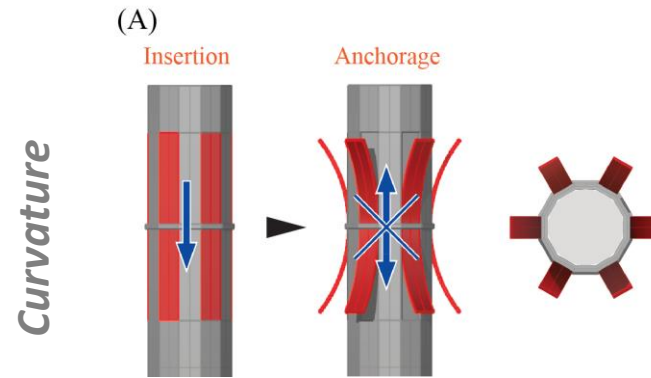
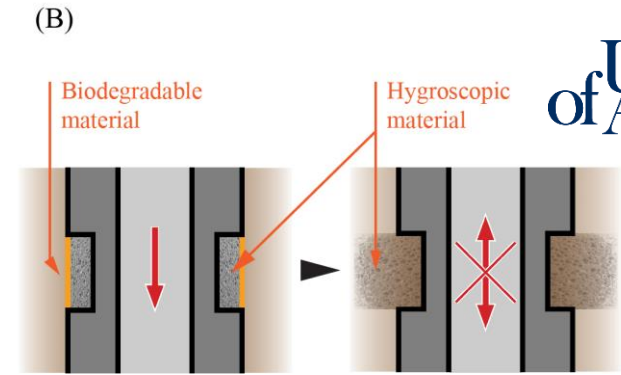
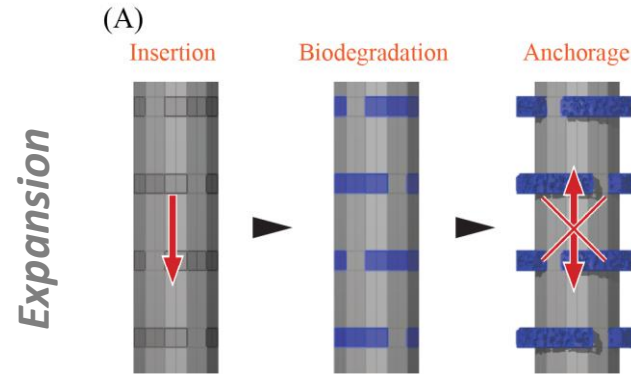
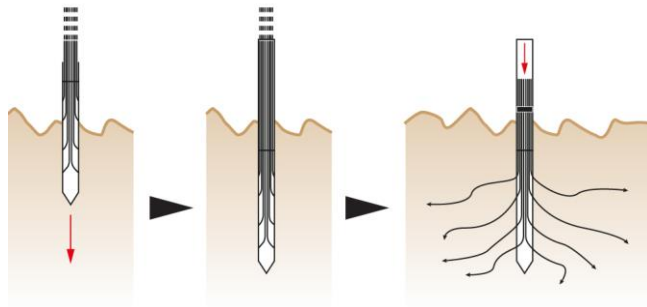
II - Concepts

Allier:
Pénétration +
Support structurel

Decaying coat

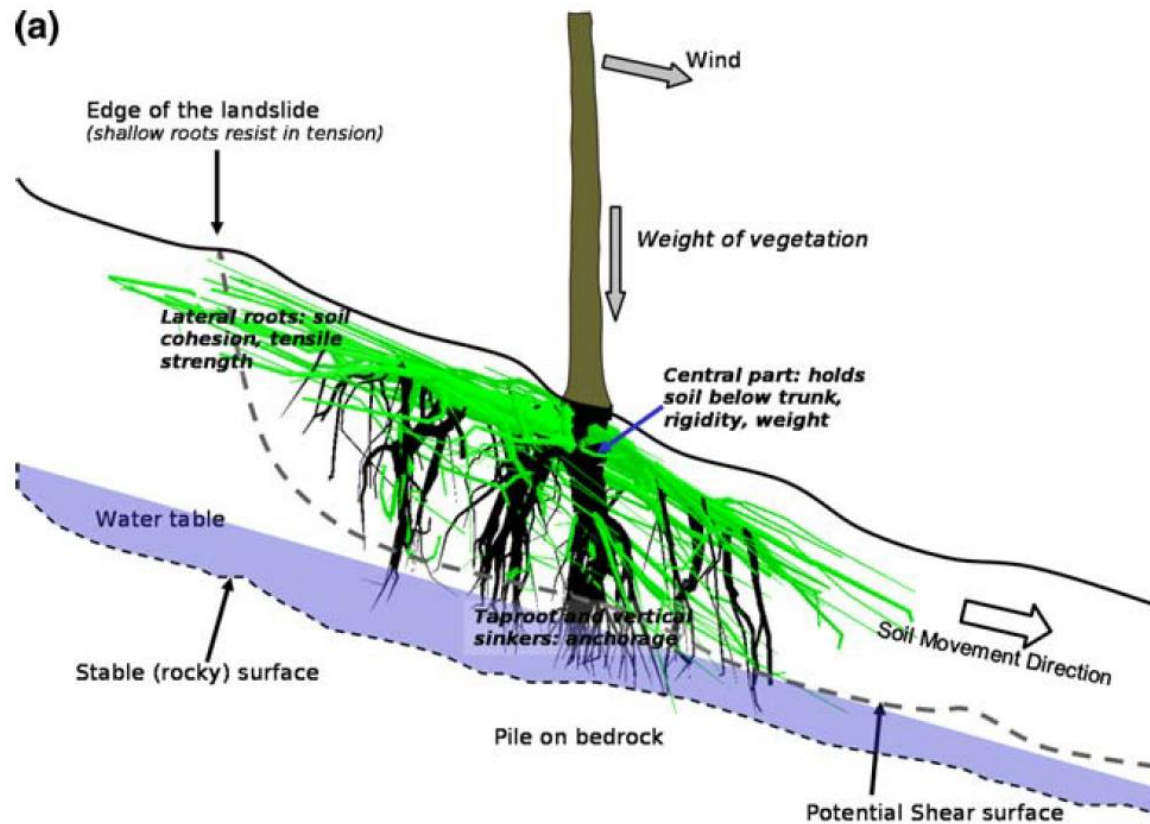


Laterals



II - Concepts

Allier: Réduction de l'érosion + Support structurel



Structure double

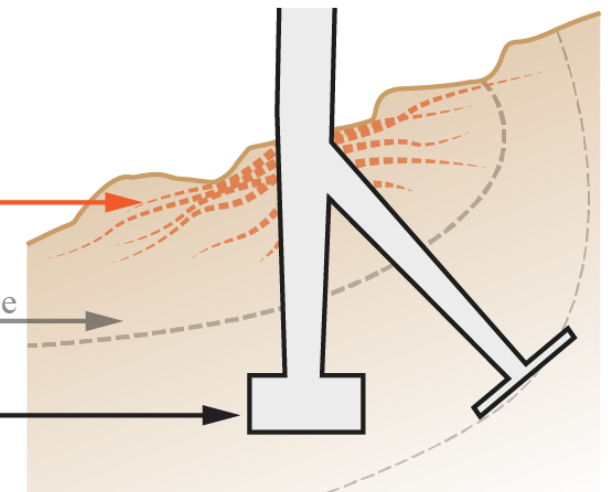
Erosion prevention

surface mesh

Potential shear surface

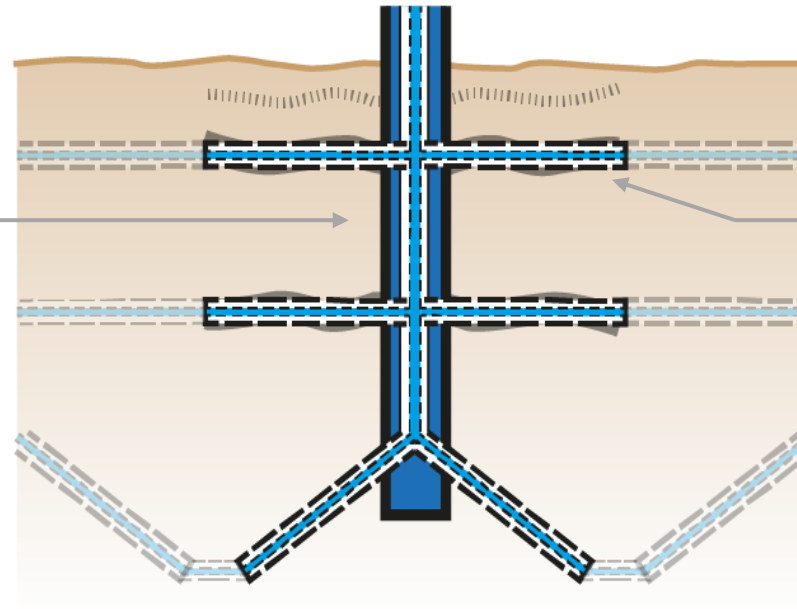
Structural support

deep piles



Reubens et al., 2007

Intégration de la multifonctionnalité



Pile verticale creuse:

- **Répartition des forces verticales**
- **Stockage** (e.g., eau)
- **Transport** (e.g., thermique)

Branches latérales creuses:

- **Répartition des forces horizontales**
- **Limiter l'érosion**
- Echange de ressources
avec le sol + entre les bâtiments
- **Greffage structurel** entre infrastructures

Principes structurels:

- Matériaux **composites auto-cicatrisants**
- **Hiérarchie** par échelles de conception



III - Biomimétisme

en faisant de la recherche fondamentale

III - Photogrammétrie pour générer des modèles 3D de racines

Processus

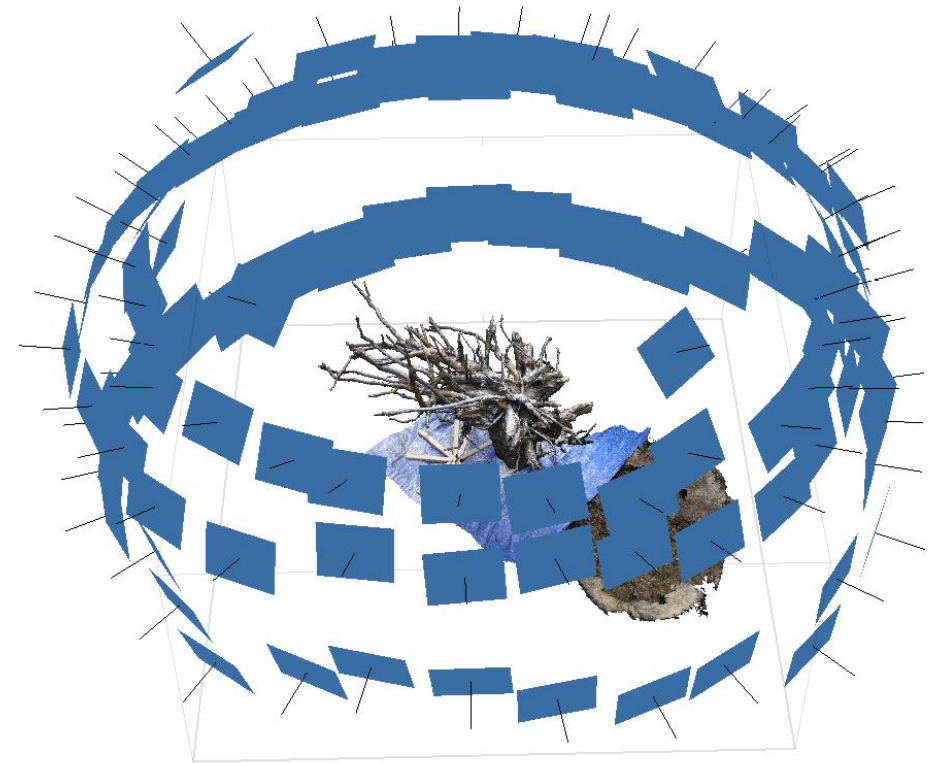
photos d'un objet avec différents angles de vue

→ logiciel de reconstruction

→ modèle 3D de l'objet

Objectifs principaux

- Faciliter la collecte de modèles 3D de racines d'arbres sur le terrain
- Comparer l'adaptation de différentes espèces à divers environnements



III - Photogrammétrie pour générer des modèles 3D de racines

Préparer



Photographier



Reconstruire

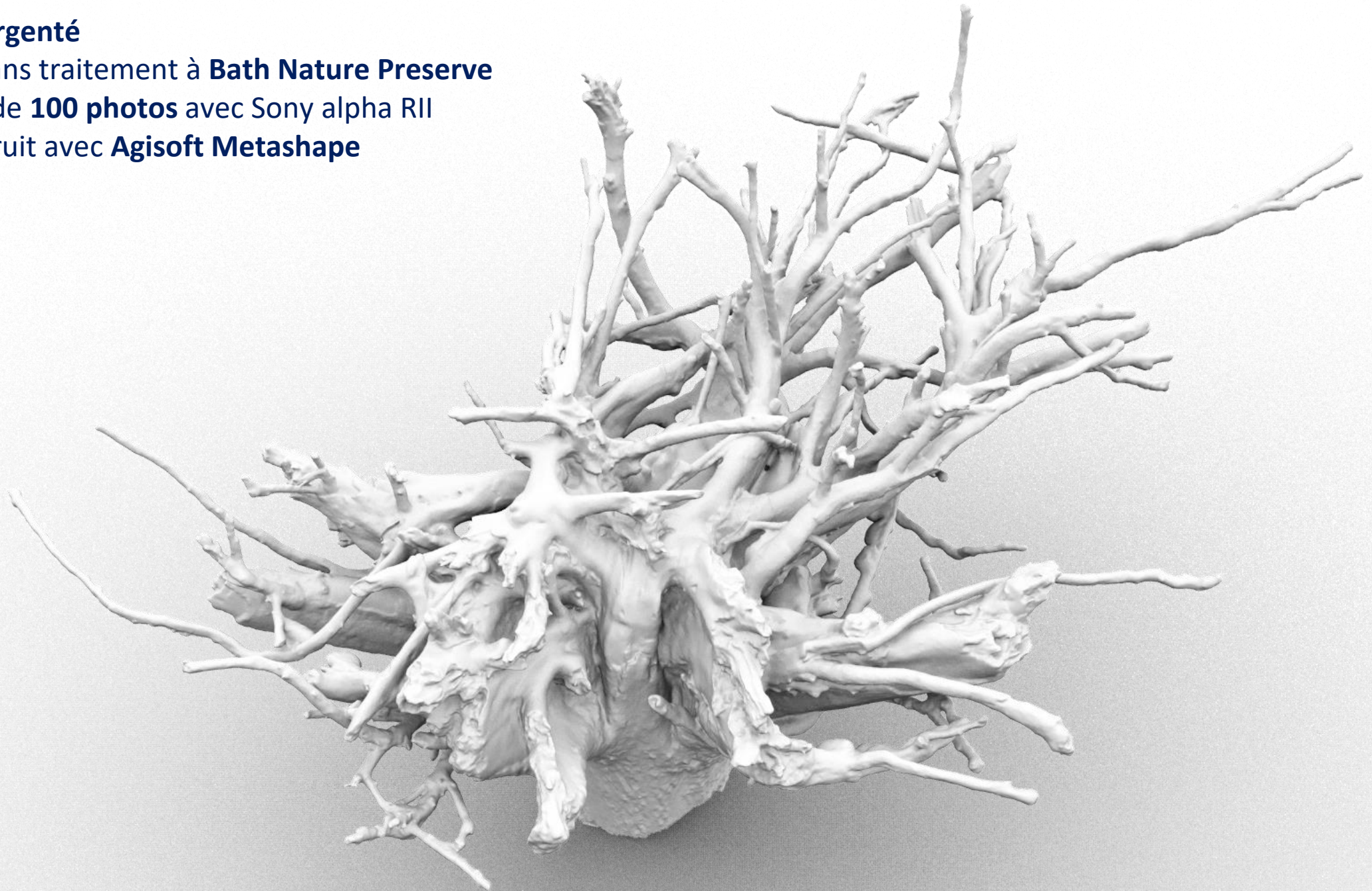


Erable argenté

Imagé sans traitement à **Bath Nature Preserve**

à partir de **100 photos** avec Sony alpha RII

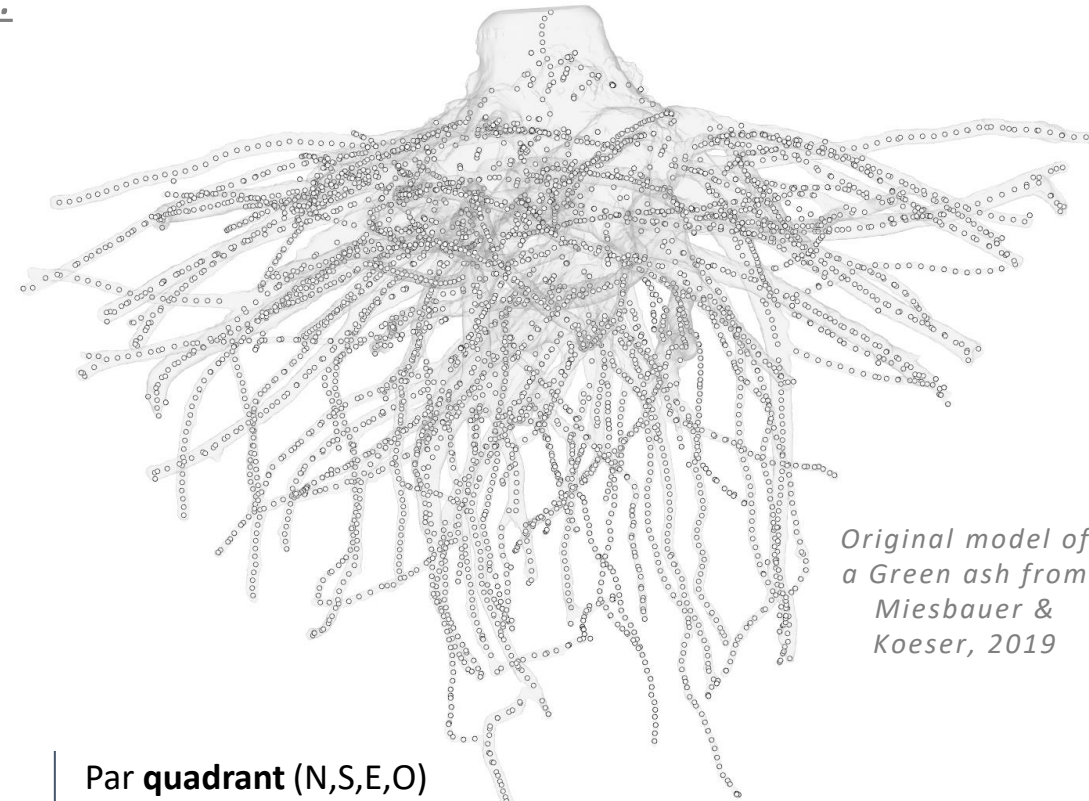
Reconstruit avec **Agisoft Metashape**



III - Extraire les caractéristiques racinaires des modèles 3D

Développement d'un algorithme avec Rhinoceros/Grasshopper:

Modèle 3D → Squelette → Analyse des caractéristiques



Original model of a Green ash from Miesbauer & Koeser, 2019

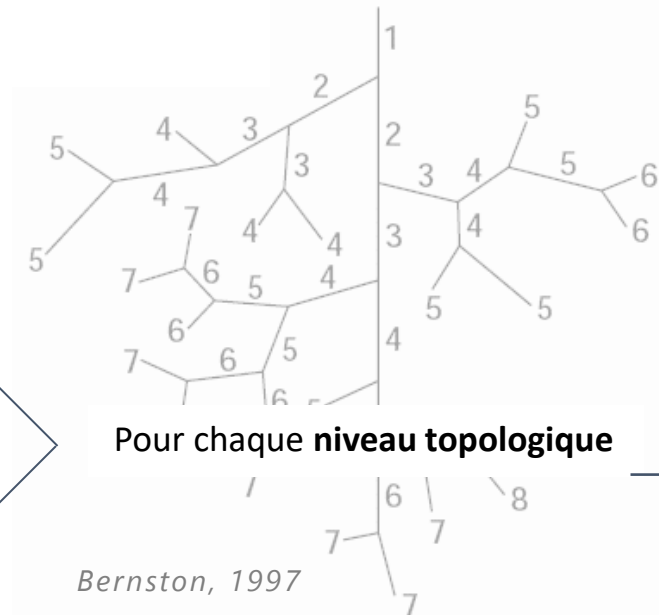
Caractéristiques des racines extraites:

Pour le système racinaire

- Volume du système racinaire
- Surface du système racinaire
- Longueur du système racinaire
- Diamètre du tronc

Pour chaque racine individuelle

- Volume
- Surface
- Longueur
- Diamètre et section
- Courbure
- Orientation
- Angle de bifurcation



Par **quadrant** (N,S,E,O)

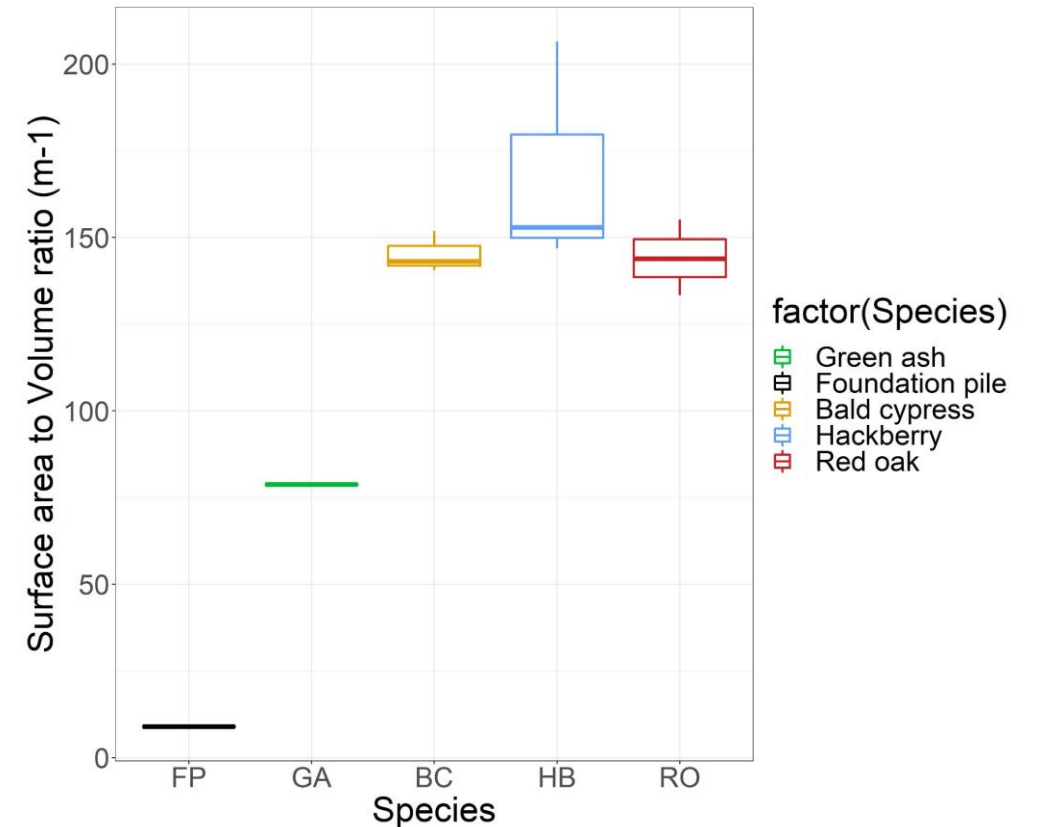
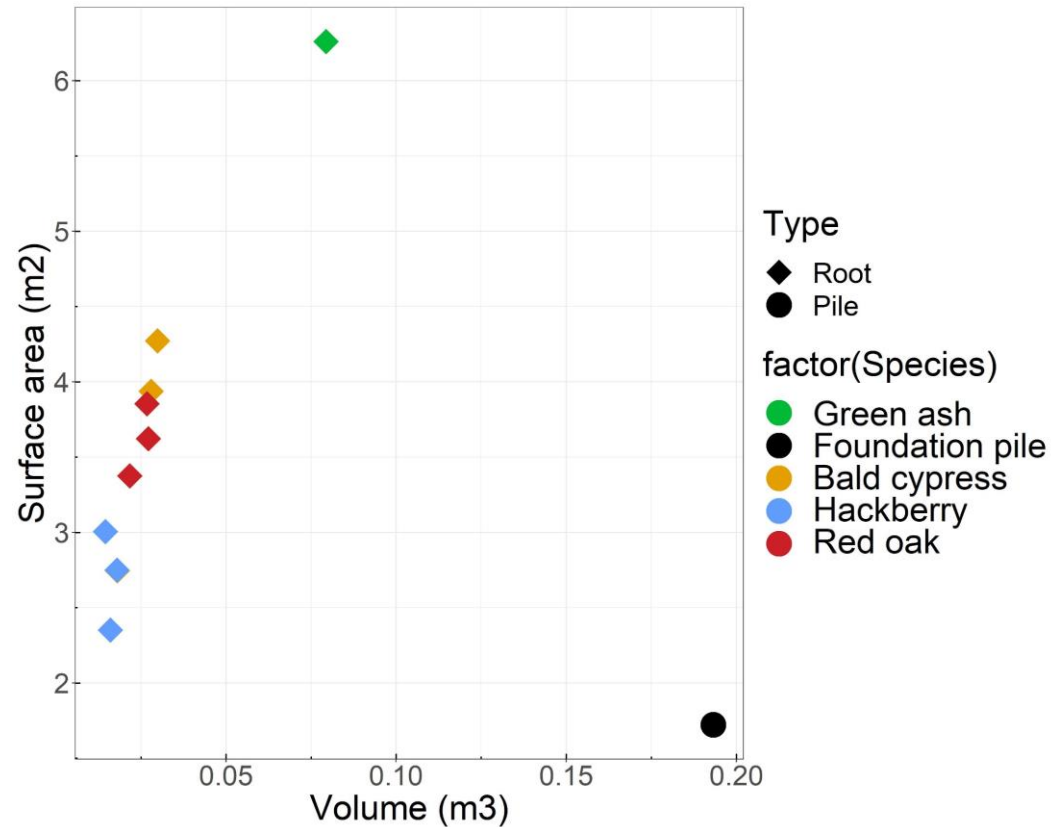
Par **distance** (Hor. Et Vert.)

Par **espèce / individu**

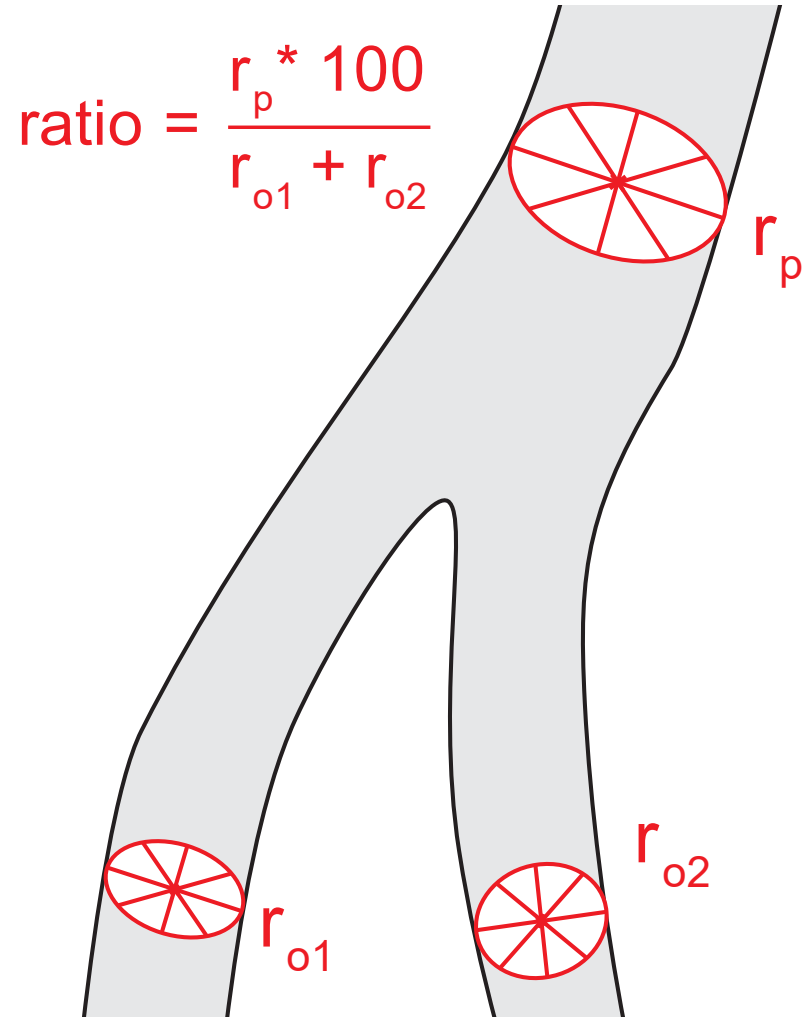
Comprendre l'
adaptation des racines

III - Extraire les caractéristiques racinaires des modèles 3D

Surface VS Volume: entre espèces et comparées à une fondation traditionnelle

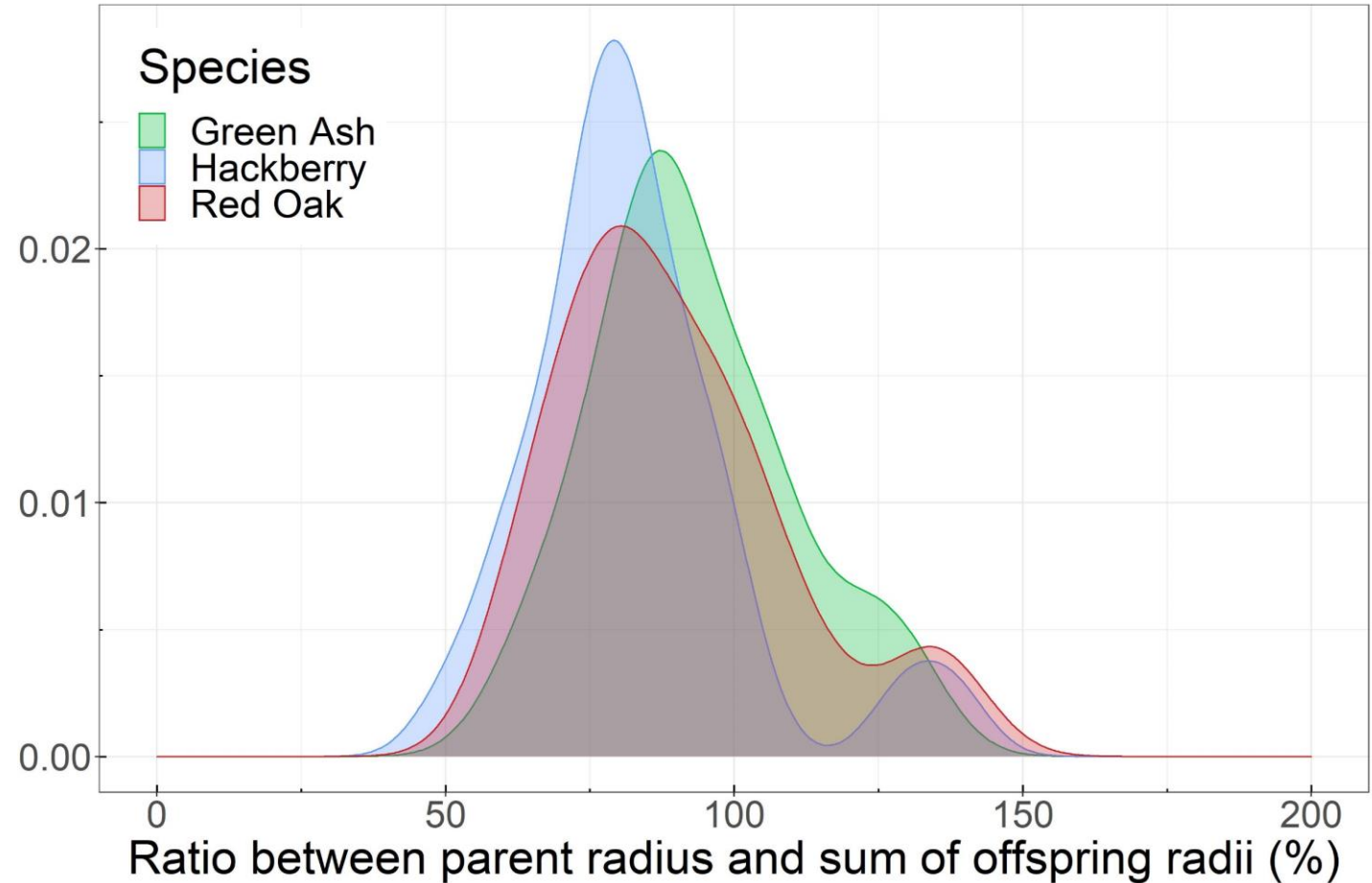
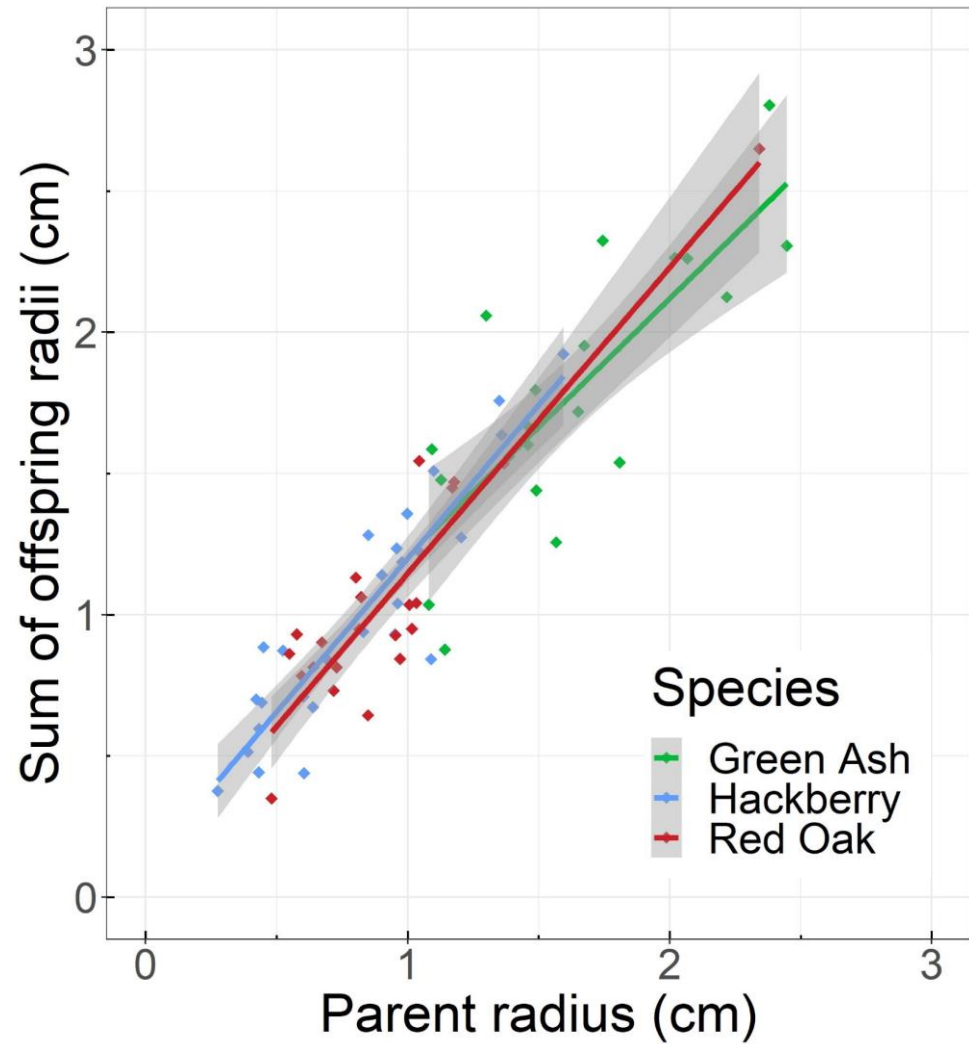


III - Extraire les caractéristiques racinaires des modèles 3D



Quel est le **ratio** entre
le **rayon d'une racine** et
la **somme des rayons de ses descendants?**

III - Extraire les caractéristiques racinaires des modèles 3D



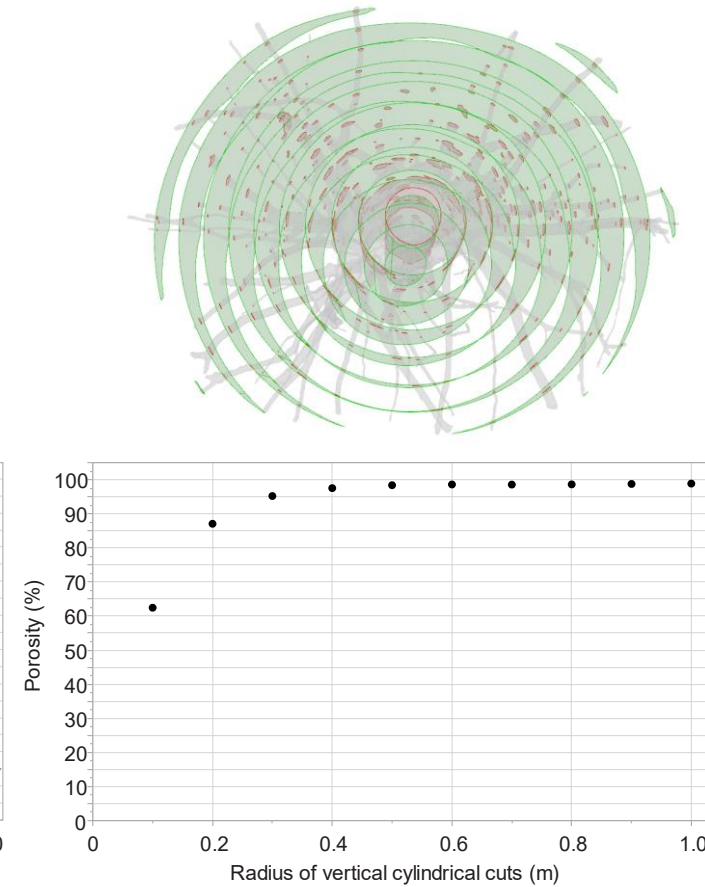
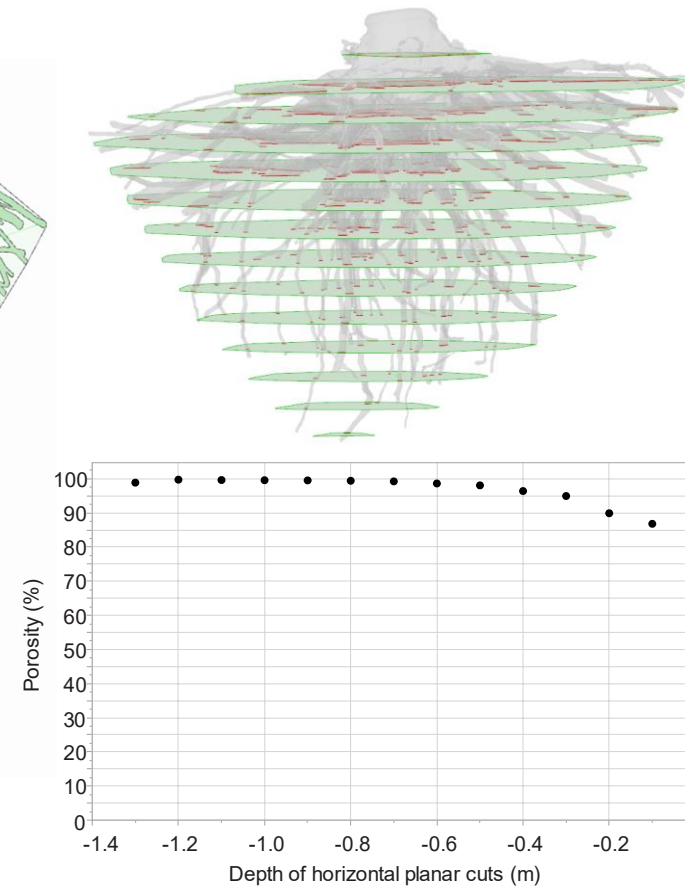
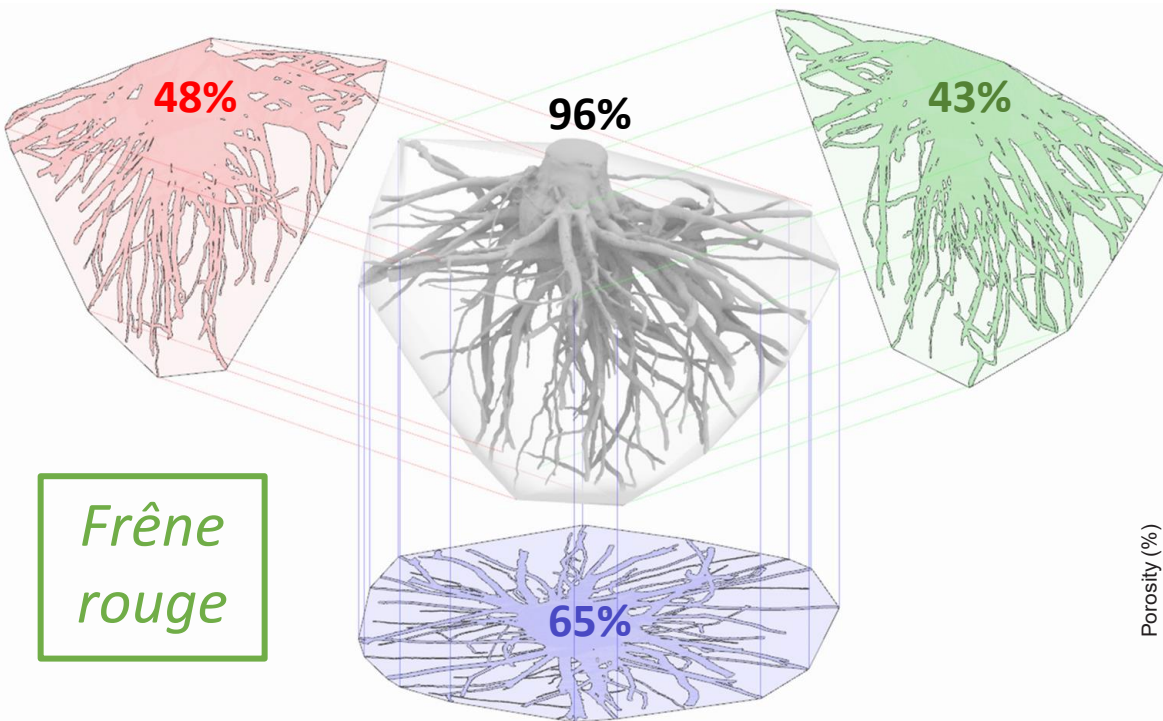
Ratio moyen = **92.57 % (Frêne rouge),**

83.05 % (Micocoulier occidental),

89.75 % (Chêne rouge)

III - Extraire les caractéristiques racinaires des modèles 3D

Comment la répartition de la matière varie (projection, profondeur, distance horizontale)?

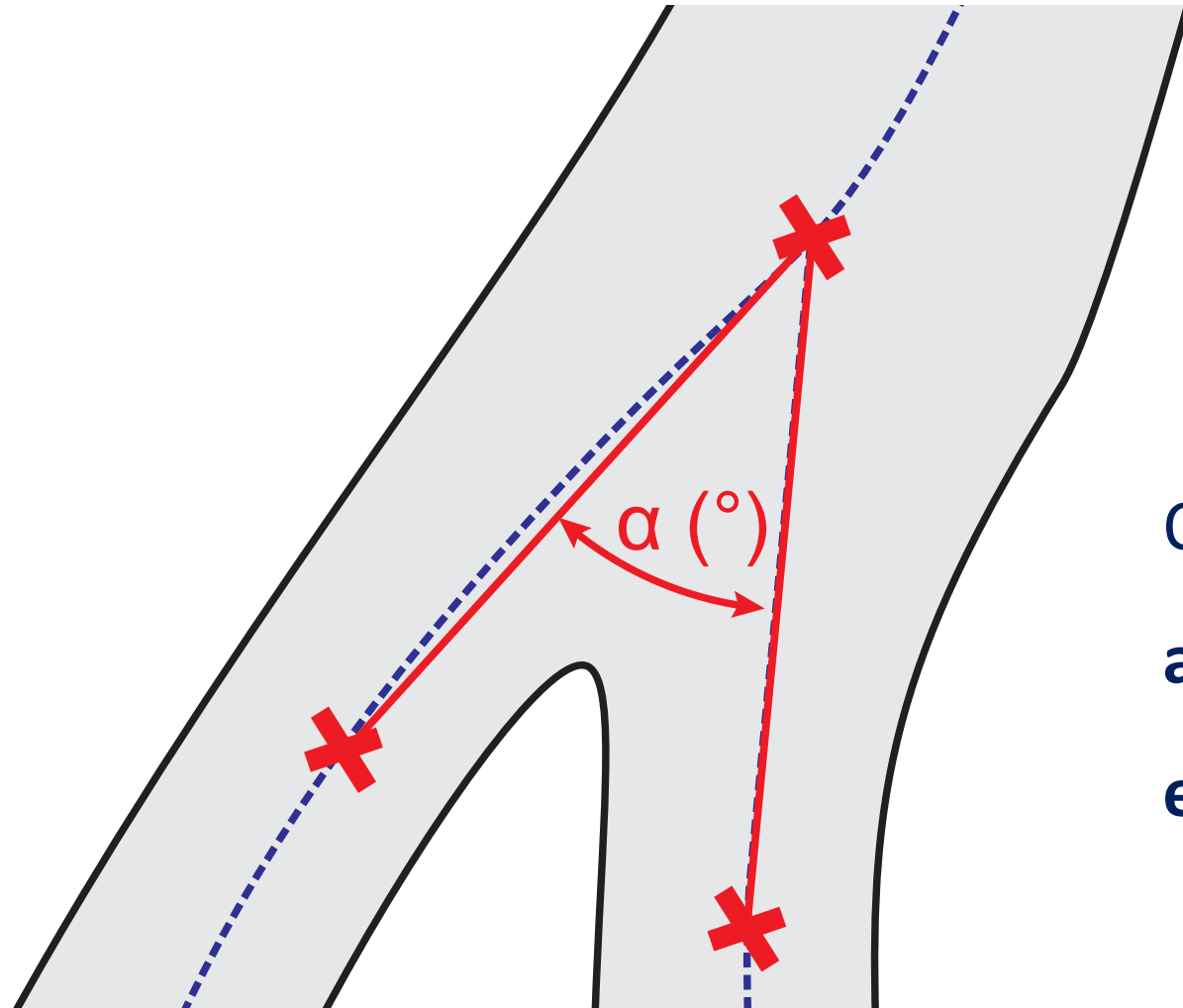


Résultats

Porosité accrue quand vu du dessus

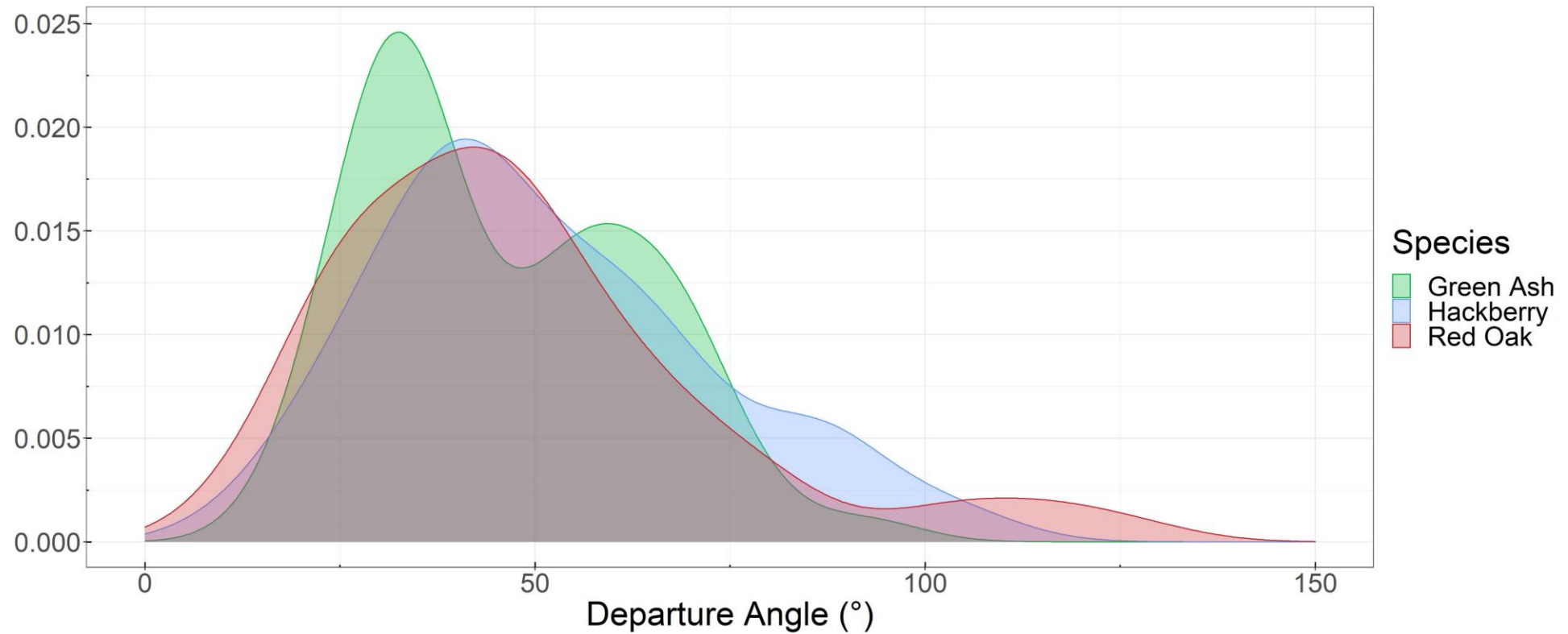
Augmentation rapide de la porosité en s'éloignant du centre

III - Extraire les caractéristiques racinaires des modèles 3D



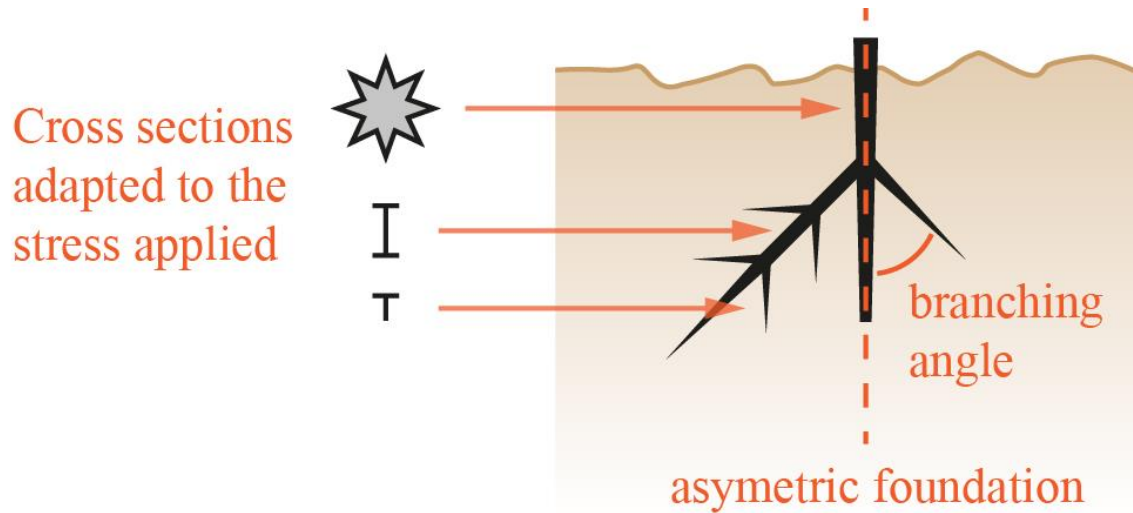
Quelle est la **répartition** des **angles de bifurcation** aux **embranchements** ?

III - Extraire les caractéristiques racinaires des modèles 3D



III - Concepts

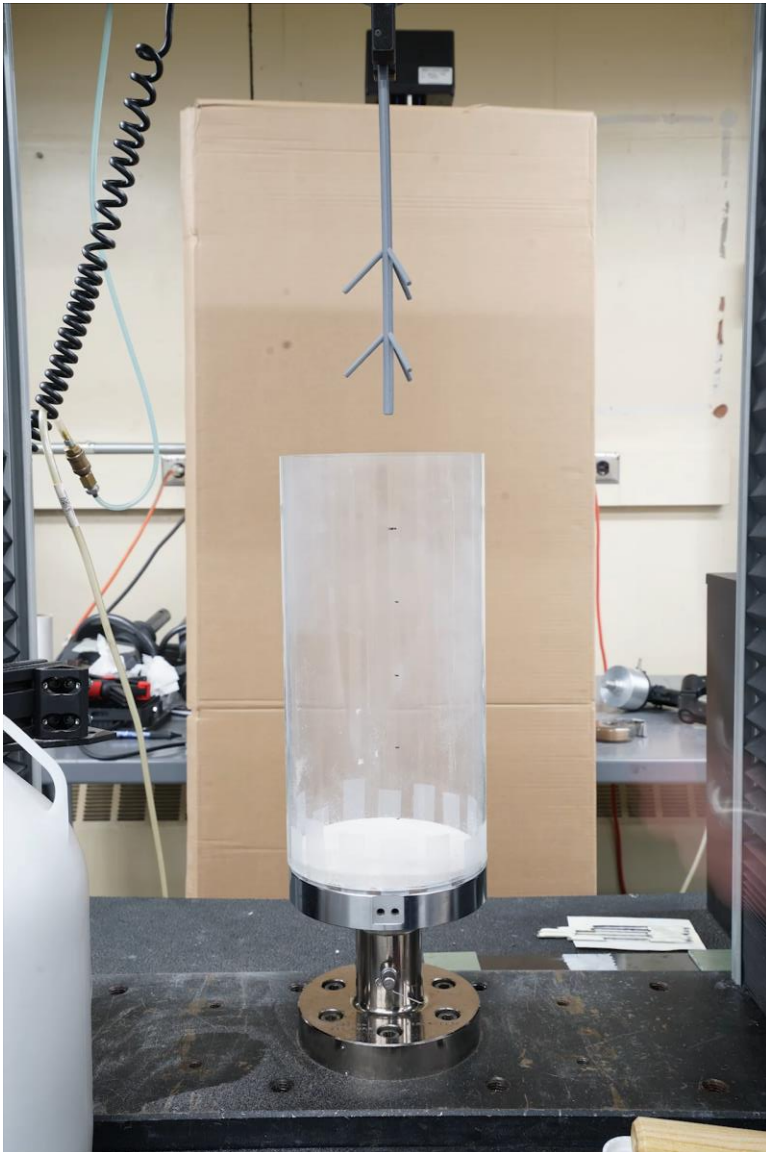
Morphologie adaptable à l'environnement



Caractéristiques d'intérêt

| | | | | | |
|--------------------------------|-----|-----|----|-----|-----|
| Longueur des racines latérales | | A-1 | A0 | A+1 | |
| Nombre de noeuds | B-2 | | B0 | B+1 | B+2 |
| Nombre de latérales à un noeud | C-2 | C-1 | C0 | C+1 | |
| Angle des latérales | | | D0 | D+1 | D+2 |
| Section des latérales | E-2 | E-1 | E0 | E+1 | E+2 |

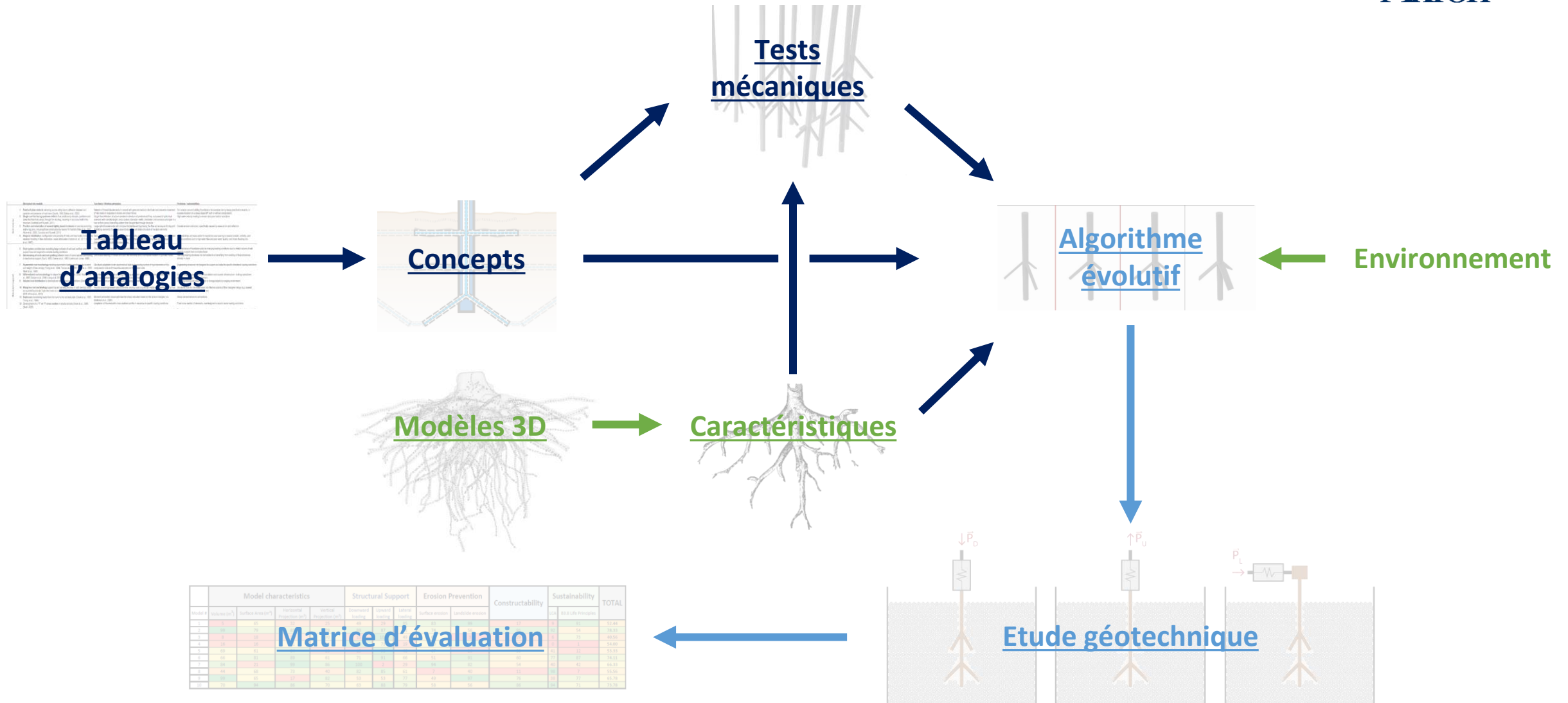
III - Evaluation des caractéristiques d'intérêt par tests mécaniques





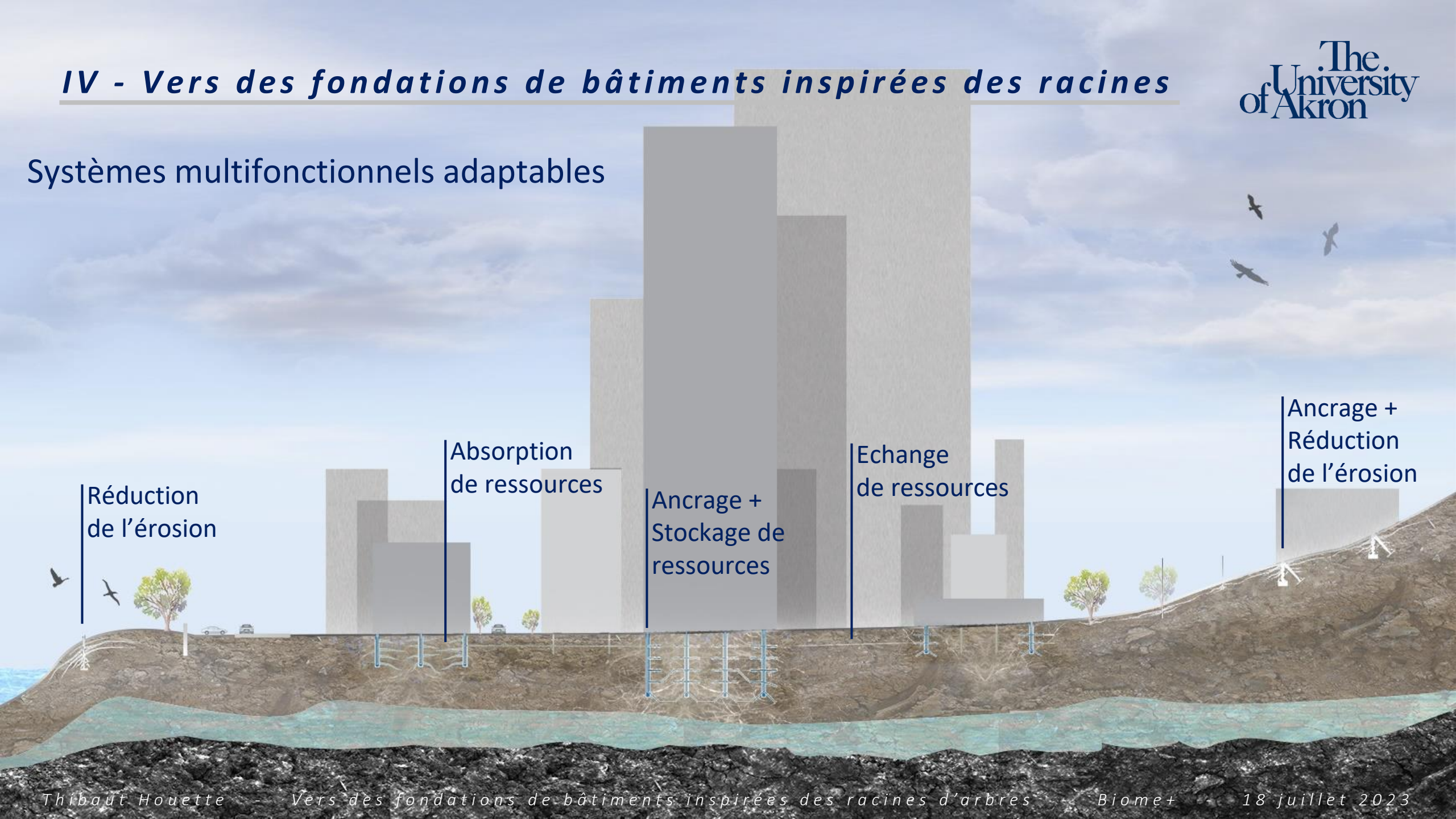
IV – Combiner les deux approches

IV - Vers des fondations de bâtiments inspirées des racines



IV - Vers des fondations de bâtiments inspirées des racines

Systemes multifonctionnels adaptables



Réduction de l'érosion

Absorption de ressources

Ancrage + Stockage de ressources

Echange de ressources

Ancrage + Réduction de l'érosion

Remerciements

Membres du Biodesign lab :

- **Assoc. Prof. Dr. Petra Gruber** (Directrice de thèse)
- **Elena Stachew** (Doctorante en biomimétisme)
- **Dr. Ari Rupp** (Procter & Gamble)
- **Claudia Naményi**
- **Brian Foresi**
- **Remik Niewiarowski**] (étudiants parrainés)

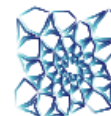
Ainsi que ...

- **Dr. Hunter King** (Co-directeur de thèse, The University of Akron, OH)
- **Dr. Hazel Barton** (The University of Akron, OH)
- **Dr. Jake Miesbauer** (Morton Arboretum, IL)
- **Dr. Nariman Mahabadi** (The University of Akron, OH)

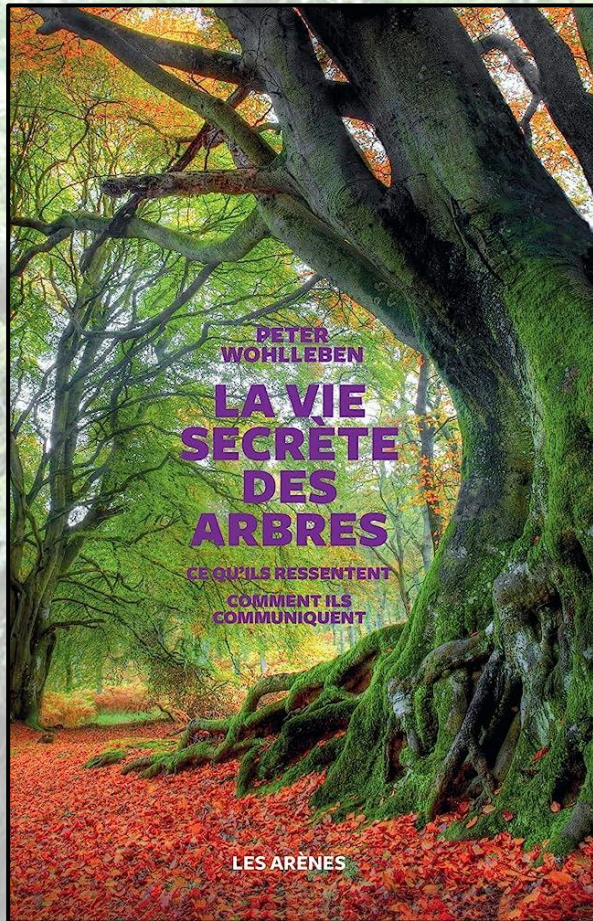
- **Dr. Julian Tao** (University of Arizona, AZ)
- **Meron Dibia** (Doctorante en biomimétisme, NJ)
- **Dr. Henry Astley** (The University of Akron, OH)
- **Dr. Randy Mitchell** (The University of Akron, OH)
- **Dr. Peter Niewiarowski** (The University of Akron, OH)
- **Dr. Lara Roketenetz** (The University of Akron, OH)
- **Debbie Ammerman** (The University of Akron, OH)



The
University
of Akron



BIOMIMICRY RESEARCH INNOVATION CENTER



Merci !

Des questions?

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Root systems research for bioinspired resilient design - a concept framework for foundation and coastal engineering

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PARAMETRIC ALGORITHMS TO EXTRACT ROOT TRAITS FOR BIOLOGY AND BIOMIMICRY

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