
Stigmergic interactions and
3D nest construction in ant colonies
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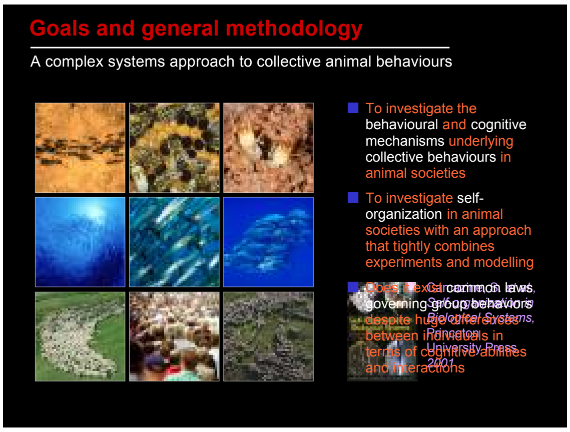
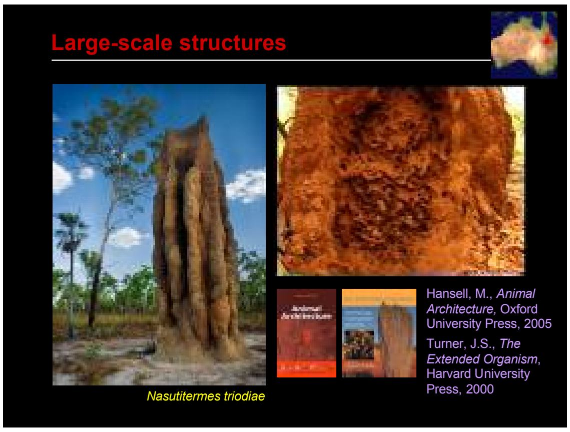
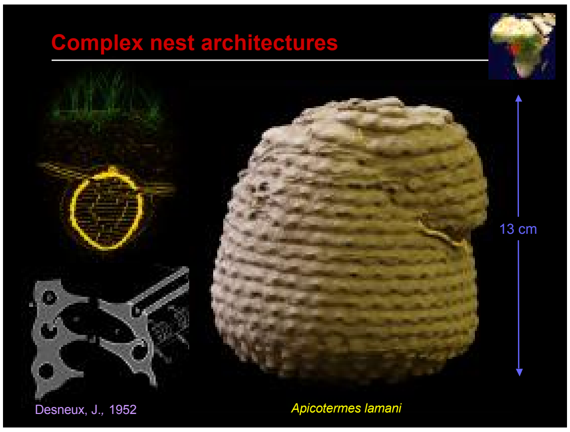
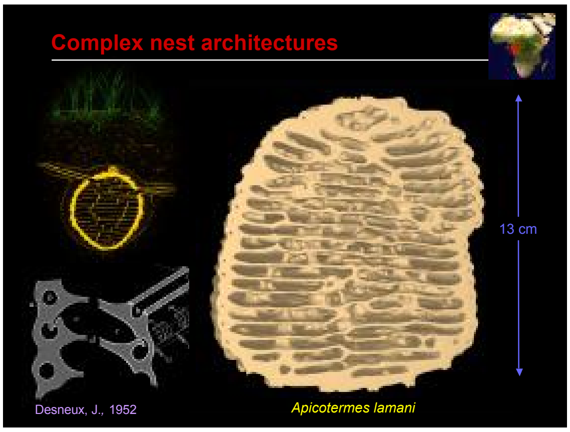
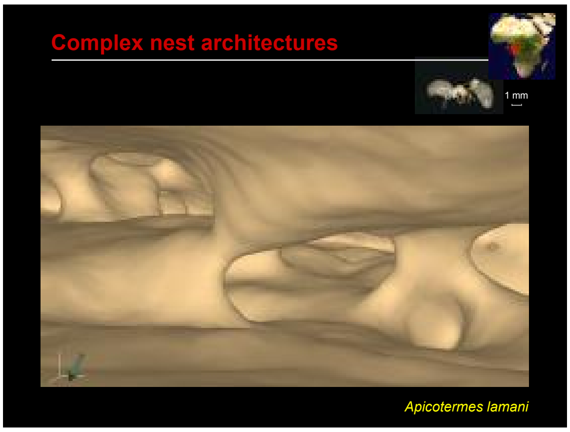
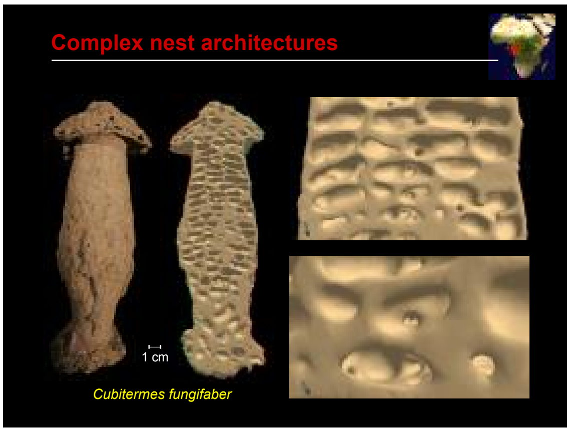

Goals and general methodology
A complex systems approach to collective animal behaviours
To investigate the behavioural and cognitive mechanisms underlying collective behaviours in animal societies
To investigate self-organization in animal societies with an approach that tightly combines experiments and modelling
common laws governing group behaviors despite huge differences between individuals in terms of cognitive abilities and interactions
Self-organization in Biological Systems,
Princeton University Press,
2001

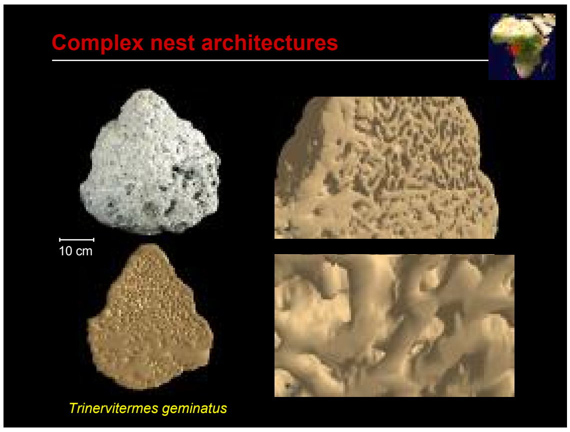

Large-scale structures
Hansell, M., Animal Architecture, Oxford University Press, 2005
Turner, J.S., The Extended Organism, Harvard University Press, 2000
Nasutitermes triodiae

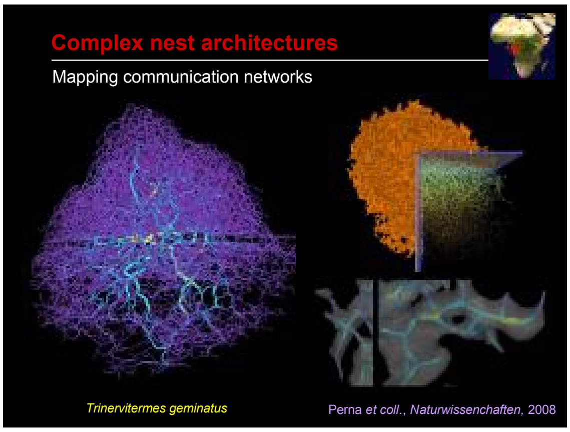

Complex nest architectures
13 cm
Desneux, J., 1952
Apicotermes lamani

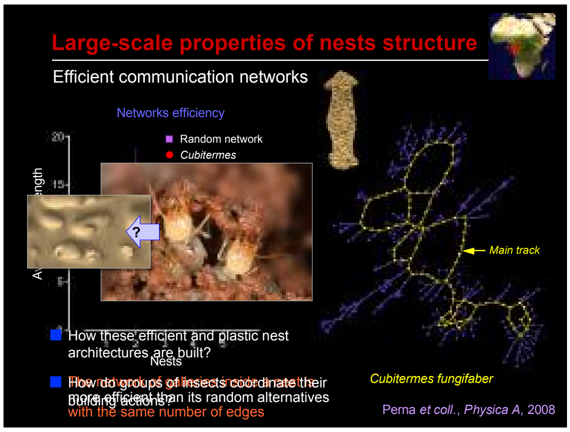

Complex nest architectures
13 cm
Desneux, J., 1952
Apicotermes lamani

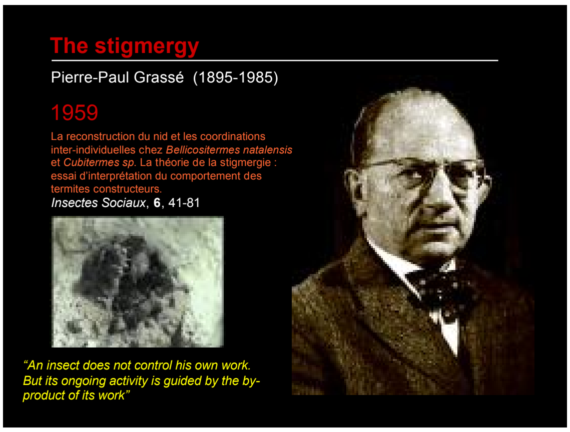

Complex nest architectures
1 mm
Apicotermes lamani

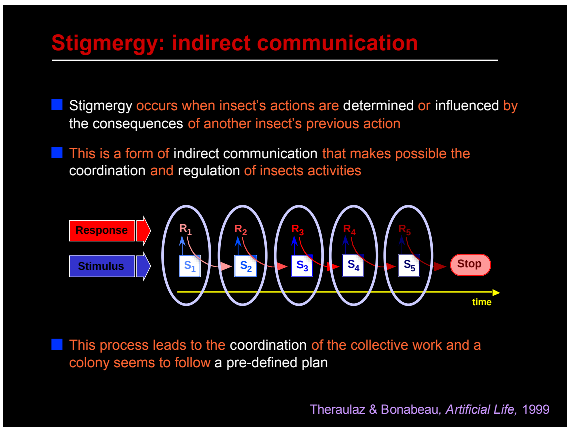

Complex nest architectures
1 cm
Cubitermes fungifaber

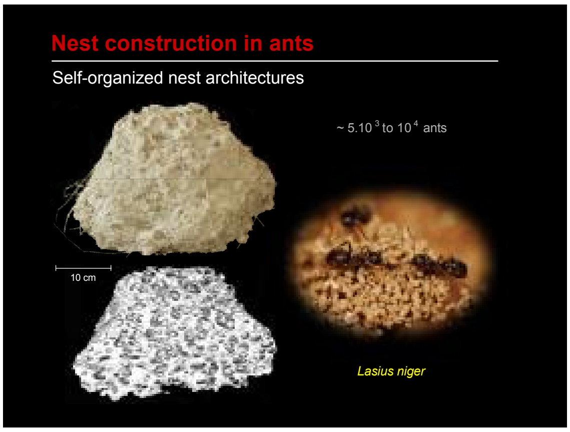

Complex nest architectures
10 cm
Trinervitermes geminatus

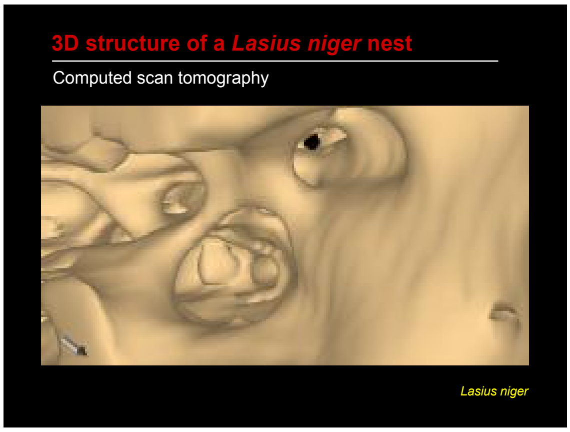

Complex nest architectures
Mapping communication networks
Trinervitermes geminatus
Perna et coll., Naturwissenchaften, 2008

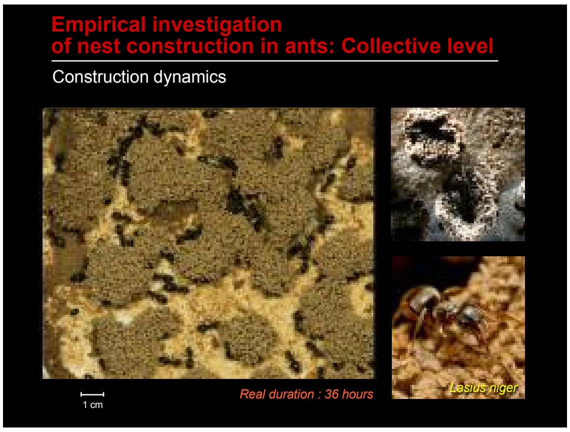

Large-scale properties of nests structure
Efficient communication networks
Networks efficiency
Random network
Cubitermes
Nests
?
How these efficient and plastic nest architectures are built?
How do groups of insects coordinate their building actions?
with the same number of edges
Main track
Cubitermes fungifaber
Perna et coll., Physica A, 2008

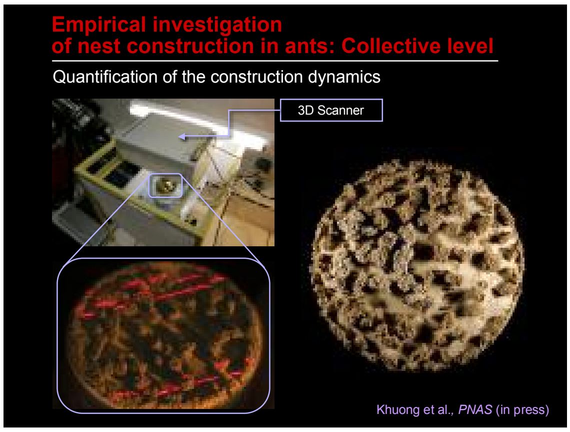

The stigmergy
Pierre-Paul Grassé (1895-1985)
1959
La reconstruction du nid et les coordinations inter-individuelles chez Bellicositermes natalensis et Cubitermes sp. La théorie de la stigmergie : essai d'interprétation du comportement des termites constructeurs.
Insectes Sociaux, 6, 41-81
"An insect does not control his own work. But its ongoing activity is guided by the by-product of its work"

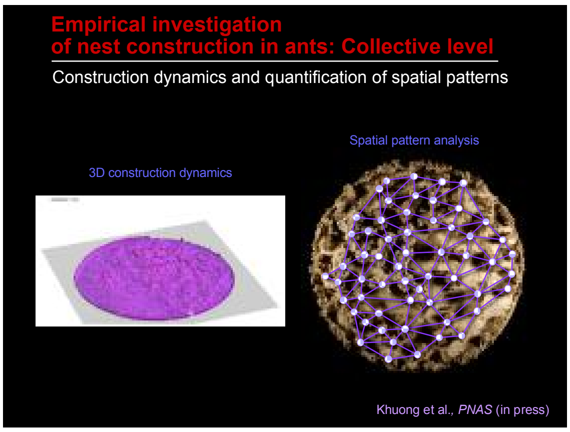

Stigmergy: indirect communication
Stigmergy occurs when insect's actions are determined or influenced by the consequences of another insect's previous action
This is a form of indirect communication that makes possible the coordination and regulation of insects activities
Response
Stimulus
R1 R2 R3 R4 R5
S1 S2 S3 S4 S5
Stop
time
This process leads to the coordination of the collective work and a colony seems to follow a pre-defined plan
Theraulaz & Bonabeau, Artificial Life, 1999

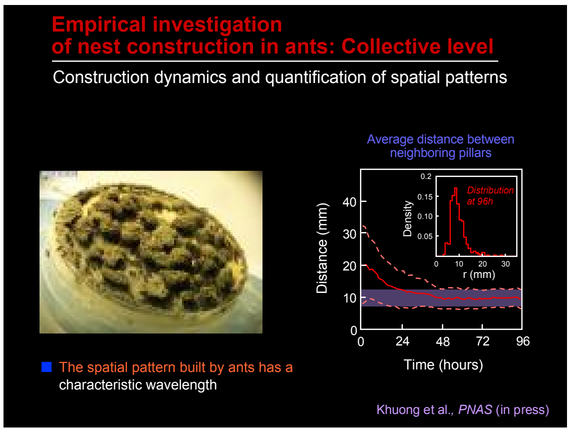

Nest construction in ants
Self-organized nest architectures
~ 5.10 3 to 10 4 ants
10 cm
Lasius niger


3D structure of a Lasius niger nest
Computed scan tomography
Lasius niger


Empirical investigation
of nest construction in ants: Collective level
Construction dynamics
1 cm
Real duration : 36 hours
Lasius niger

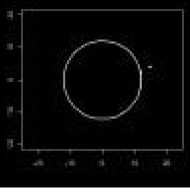

Empirical investigation
of nest construction in ants: Collective level
Quantification of the construction dynamics
3D Scanner
Khuong et al., PNAS (in press)

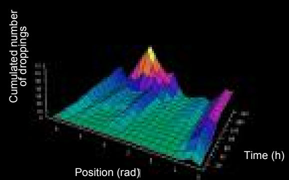

Empirical investigation
of nest construction in ants: Collective level
Construction dynamics and quantification of spatial patterns
3D construction dynamics
Spatial pattern analysis
Khuong et al., PNAS (in press)


Empirical investigation
of nest construction in ants: Collective level
Construction dynamics and quantification of spatial patterns
Average distance between
neighboring pillars
Distance (mm)
Time (hours)
Density
r (mm)
Distribution
at 96h
The spatial pattern built by ants has a
characteristic wavelength
Khuong et al., PNAS (in press)

Empirical investigation of nest construction in ants: Individual level

Construction mechanisms: picking up and dropping behaviors





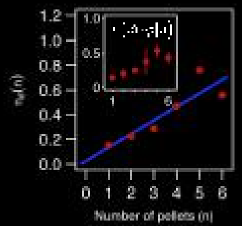
- The deposition of soil pellets in a place stimulates ants to accumulate more building material through a positive feed-back

Empirical investigation of nest construction in ants: Individual level

Construction mechanisms: picking up and dropping behaviors

Quantification of deposition and picking up behaviors

Rate of deposition and probability of depositing a soil pellet (inset)



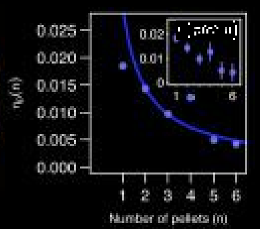
- [illegible] is estimated by the ratio of the number of depositions to the total number of contacts that ants carrying a pellet had with a pile of that size

Khuong et al., *PNAS* (in press)

Empirical investigation of nest construction in ants: Individual level

Construction mechanisms: picking up and dropping behaviors

Rate of deposition and probability of depositing a soil pellet (inset)

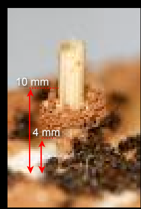


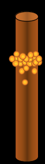
- To determine [illegible] we estimated the contact rate of unloaded ants with a pile of size *n* and the rate of change of that pile after a contact with an ant

Khuong et al., *PNAS* (in press)

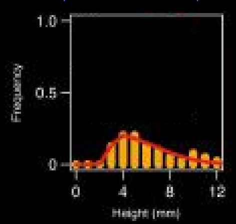
Empirical investigation of nest construction in ants: Individual level

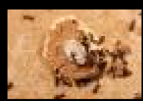
Construction mechanisms: body templates





Probability of dropping a building particle on the side of a pillar



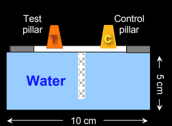


- When a pillar reaches a critical height ants start to build lateral extensions

Khuong et al., *PNAS* (in press)

Empirical investigation of nest construction in ants: Individual level

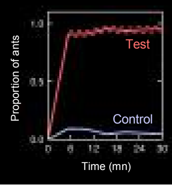
Construction mechanisms: building pheromone



- Ants add a pheromone to the building material
- This chemical signal has a retention effect on the ants and concentrates the depositions of pellets on recently deposited pellets
- This effect has a limited duration

Control pillar

Test pillar



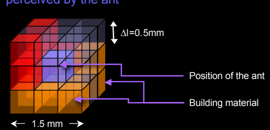
Khuong et al., *PNAS* (in press)

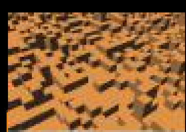
3D computational model of ant nest construction

Model description

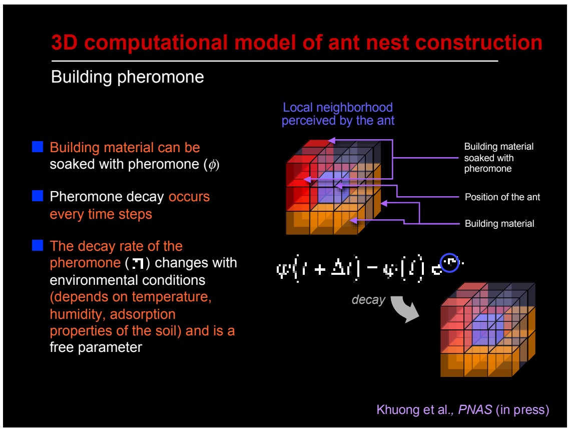
- Ants are modeled by asynchronous automata with a stimulus-response behavior
- Ants move according to a constrained random walk: they stay in contact with the surface of the built structure
- Virtual ants have a local perception of their environment (the first 26 neighboring cells close the cell occupied by the ants)

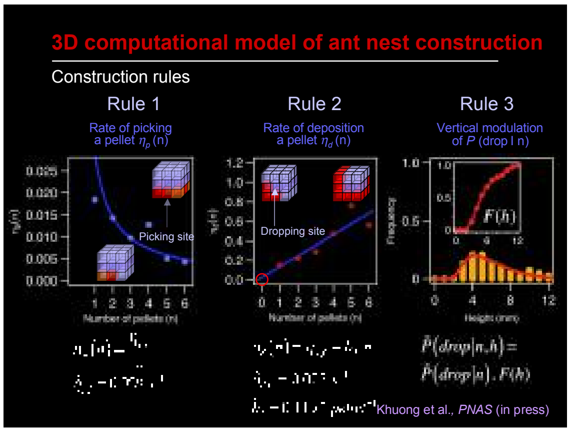
Local neighborhood perceived by the ant

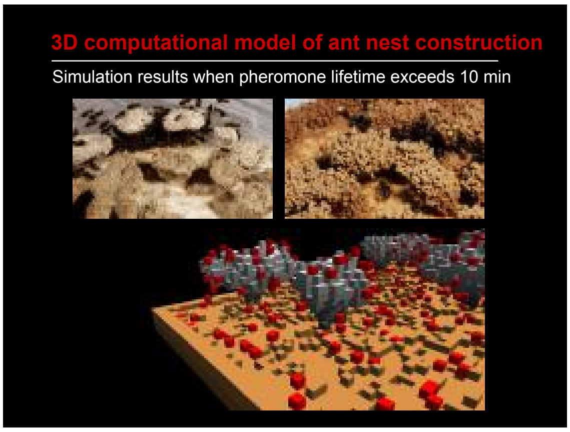


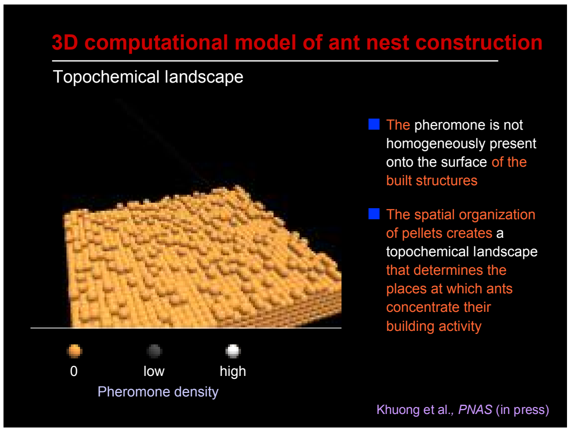


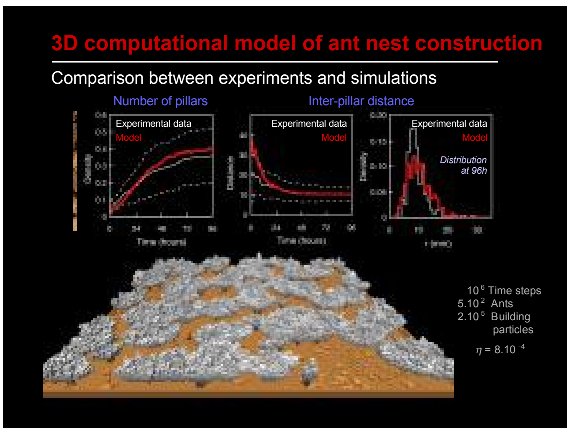
Khuong et al., *PNAS* (in press)

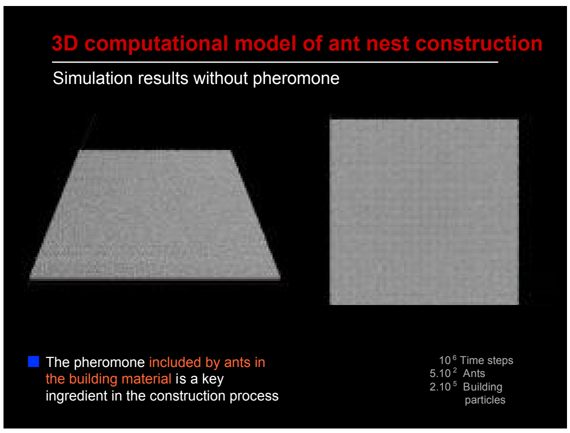

3D computational model of ant nest construction
Building pheromone
Local neighborhood perceived by the ant
Building material can be soaked with pheromone (φ)
Pheromone decay occurs every time steps
The decay rate of the pheromone changes with environmental conditions (depends on temperature, humidity, adsorption properties of the soil) and is a free parameter
Building material soaked with pheromone
Position of the ant
Building material
decay
Khuong et al., PNAS (in press)

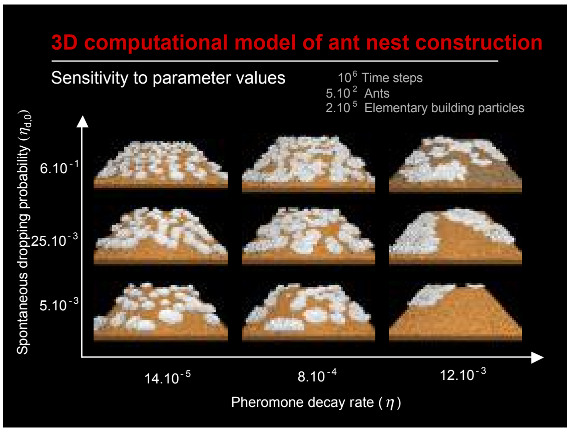

3D computational model of ant nest construction
Construction rules
Rule 1
Rate of picking a pellet
Picking site
Number of pellets (n)
Rule 2
Rate of deposition a pellet
Dropping site
Number of pellets (n)
Rule 3
Vertical modulation of P (drop I n)
F(h)
Frequency
Height (mm)
Khuong et al., PNAS (in press)

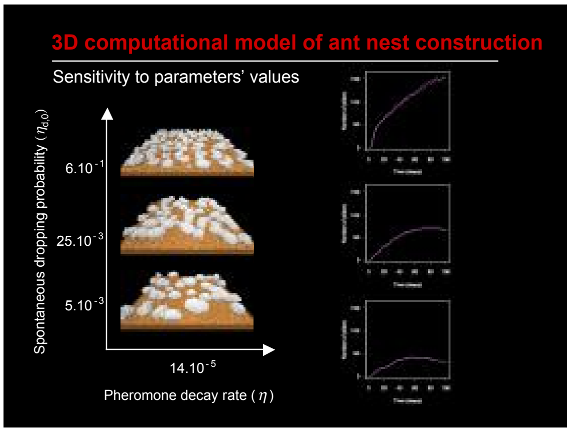

3D computational model of ant nest construction
Simulation results when pheromone lifetime exceeds 10 min

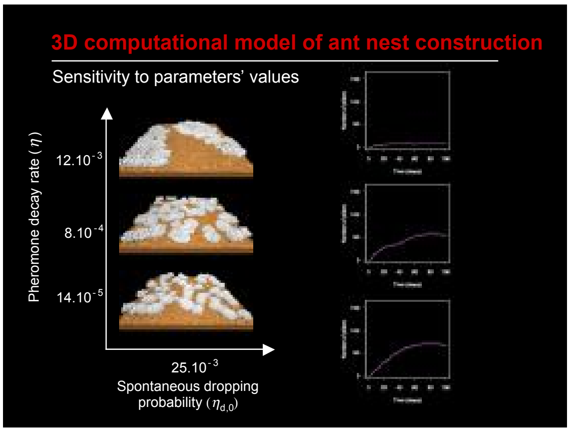

3D computational model of ant nest construction
Topochemical landscape
The pheromone is not homogeneously present onto the surface of the built structures
The spatial organization of pellets creates a topochemical landscape that determines the places at which ants concentrate their building activity
0
low
high
Pheromone density
Khuong et al., PNAS (in press)

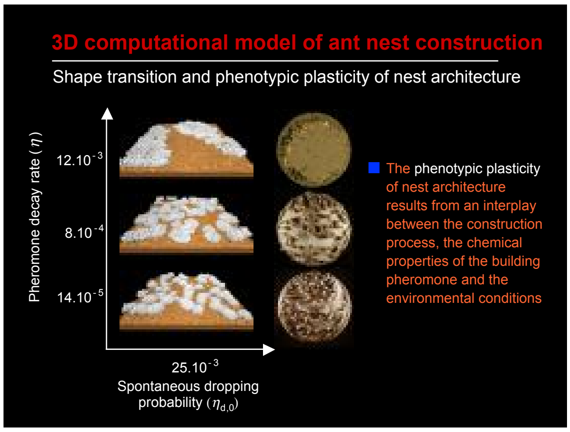

3D computational model of ant nest construction
Comparison between experiments and simulations
Number of pillars
Inter-pillar distance
Experimental data
Model
Experimental data
Model
Experimental data
Model
Distribution at 96h
Time (hours)
Time (hours)
10⁶ Time steps
5.10² Ants
2.10⁵ Building particles
η = 8.10⁻⁴

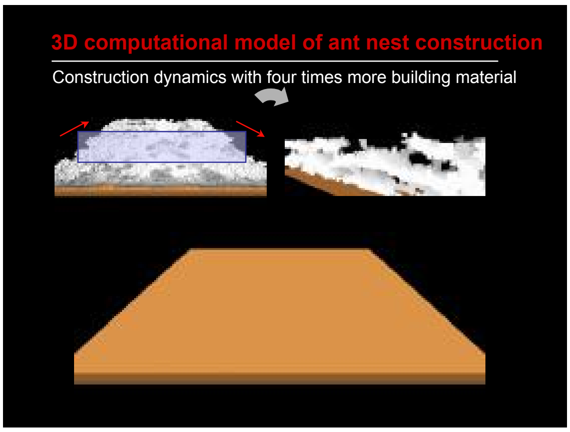

3D computational model of ant nest construction
Simulation results without pheromone
The pheromone included by ants in the building material is a key ingredient in the construction process
10⁶ Time steps
5.10² Ants
2.10⁵ Building particles

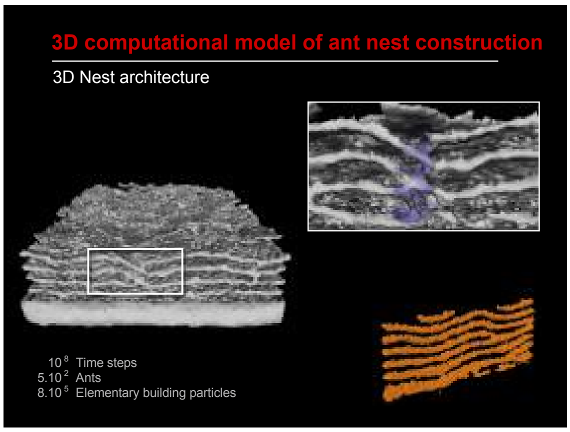

3D computational model of ant nest construction
Sensitivity to parameter values
10^6 Time steps
5.10^2 Ants
2.10^5 Elementary building particles
Spontaneous dropping probability ($\eta_{d,0}$)
6.10^{-1}
25.10^{-3}
5.10^{-3}
14.10^{-5}
8.10^{-4}
12.10^{-3}
Pheromone decay rate (η)

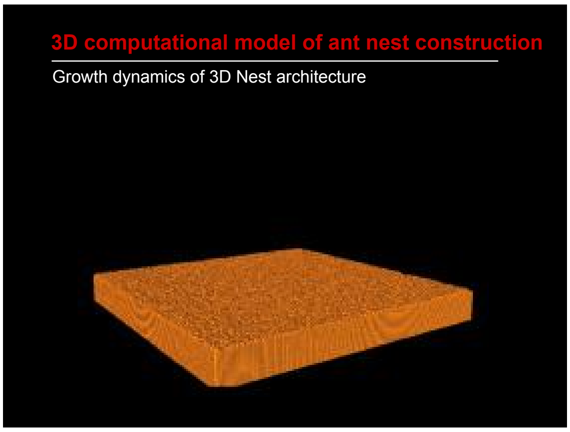

3D computational model of ant nest construction
Sensitivity to parameters' values
Spontaneous dropping probability ($\eta_{d,0}$)
6.10^{-1}
25.10^{-3}
5.10^{-3}
14.10^{-5}
Pheromone decay rate (η)

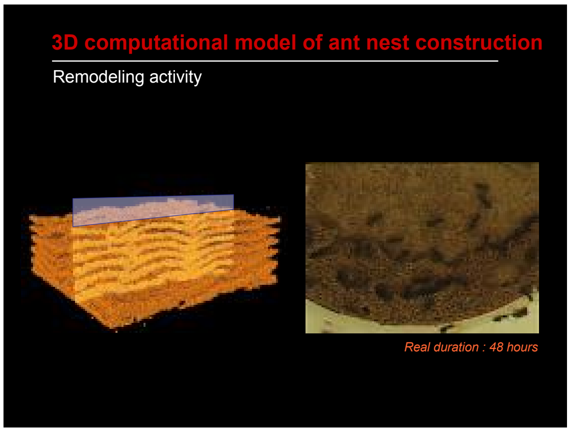

3D computational model of ant nest construction
Sensitivity to parameters' values
Pheromone decay rate (η)
12.10^{-3}
8.10^{-4}
14.10^{-5}
25.10^{-3}
Spontaneous dropping probability ($\eta_{d,0}$)

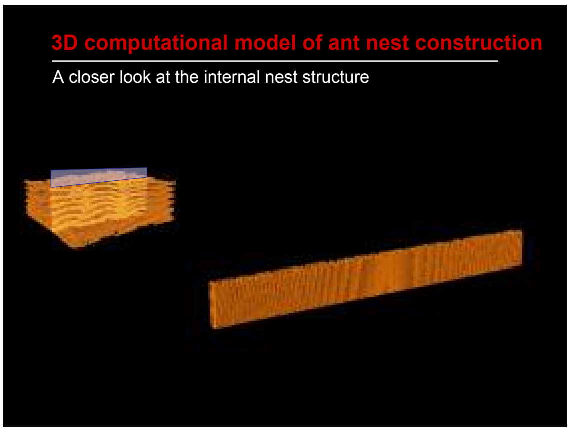

3D computational model of ant nest construction
Shape transition and phenotypic plasticity of nest architecture
Pheromone decay rate (η)
12.10^{-3}
8.10^{-4}
14.10^{-5}
25.10^{-3}
Spontaneous dropping probability ($\eta_{d,0}$)
The phenotypic plasticity of nest architecture results from an interplay between the construction process, the chemical properties of the building pheromone and the environmental conditions

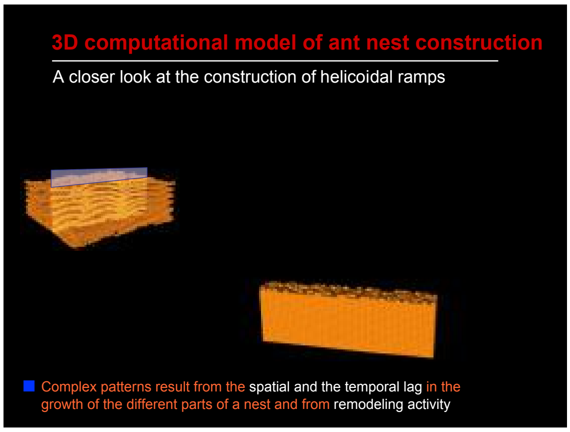

3D computational model of ant nest construction
Construction dynamics with four times more building material

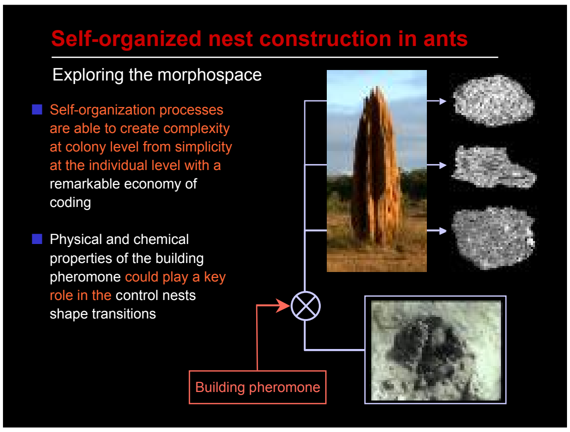

3D computational model of ant nest construction
3D Nest architecture
10^8 Time steps
5.10^2 Ants
8.10^5 Elementary building particles

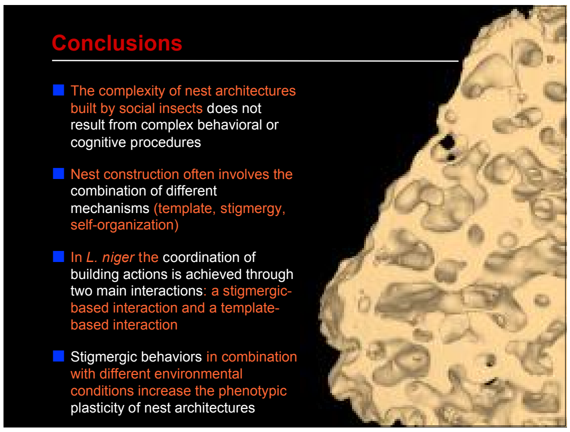

3D computational model of ant nest construction
Growth dynamics of 3D Nest architecture

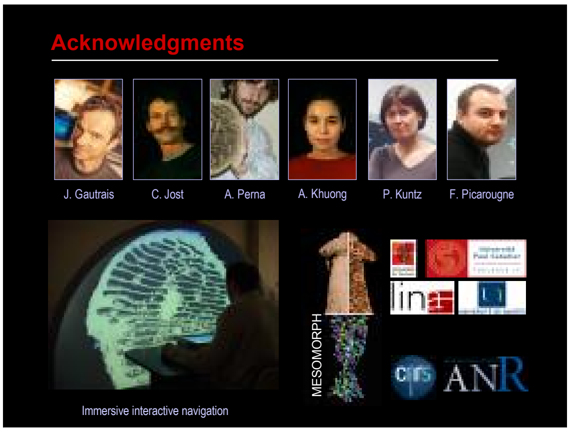

3D computational model of ant nest construction
Remodeling activity
Real duration : 48 hours


3D computational model of ant nest construction
A closer look at the internal nest structure


3D computational model of ant nest construction
A closer look at the construction of helicoidal ramps
Complex patterns result from the spatial and the temporal lag in the growth of the different parts of a nest and from remodeling activity


Self-organized nest construction in ants
Exploring the morphospace
Self-organization processes are able to create complexity at colony level from simplicity at the individual level with a remarkable economy of coding
Physical and chemical properties of the building pheromone could play a key role in the control nests shape transitions
Building pheromone


Conclusions
The complexity of nest architectures built by social insects does not result from complex behavioral or cognitive procedures
Nest construction often involves the combination of different mechanisms (template, stigmergy, self-organization)
In L. niger the coordination of building actions is achieved through two main interactions: a stigmergic-based interaction and a template-based interaction
Stigmergic behaviors in combination with different environmental conditions increase the phenotypic plasticity of nest architectures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P. Kuntz
F. Picarougne
Immersive interactive navigation
MESOMORPH
ANR


http://science-animation.itch.io/termitia-en