Participatory and Collaborative Modeling of Sustainable Systems

A Systematic Review

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istvandavid.com

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Sustainable Systems and Methods

Why Environmental Informatics?

Excerpt from Chasing Ice, https://chasingice.com/

Final Words: The Grand Challenge of our Time

"The destruction of Earth's environment is the human rights challenge of our time"

- Archbishop Desmond Tutu

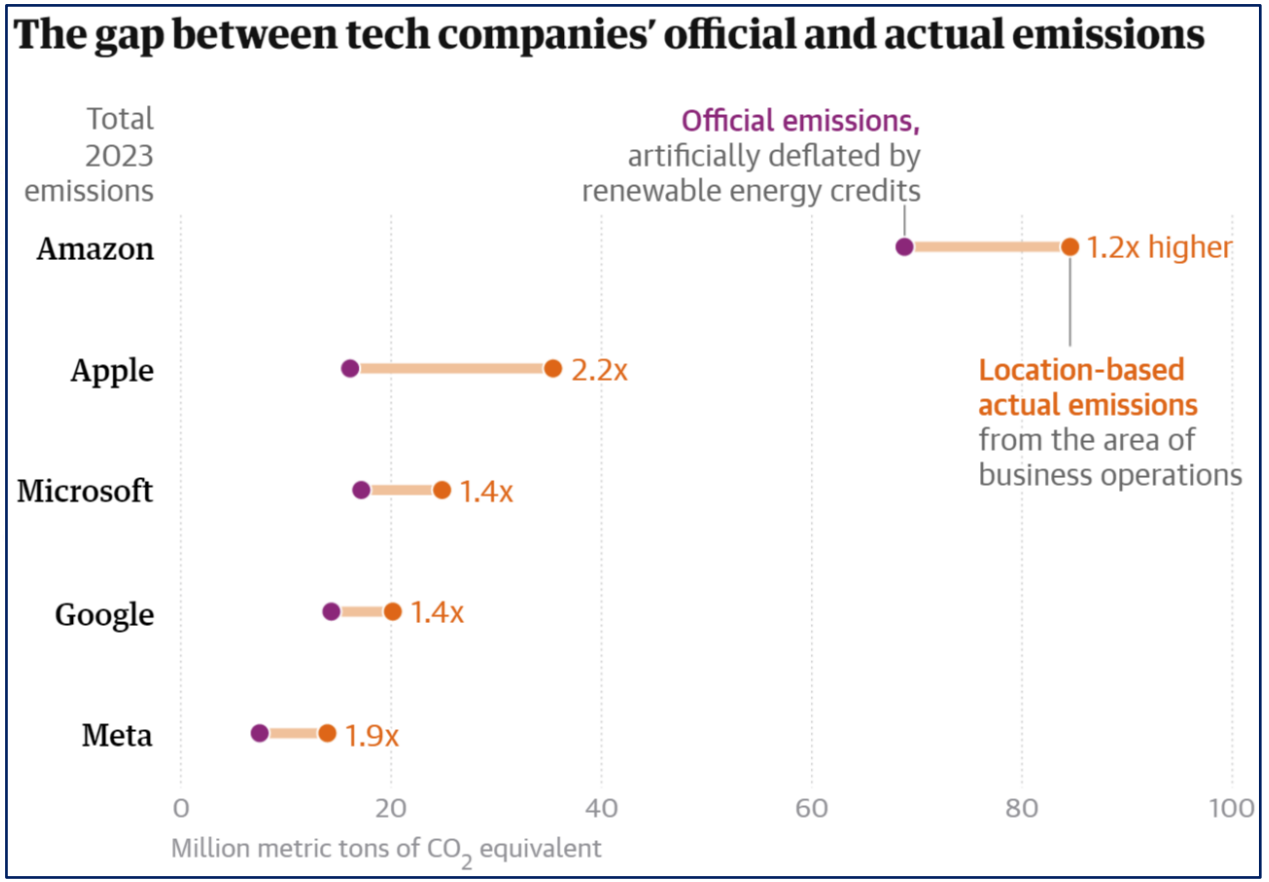
Sustainable Systems and Methods

https://istvandavid.com/lab

We need to **model** sustainability

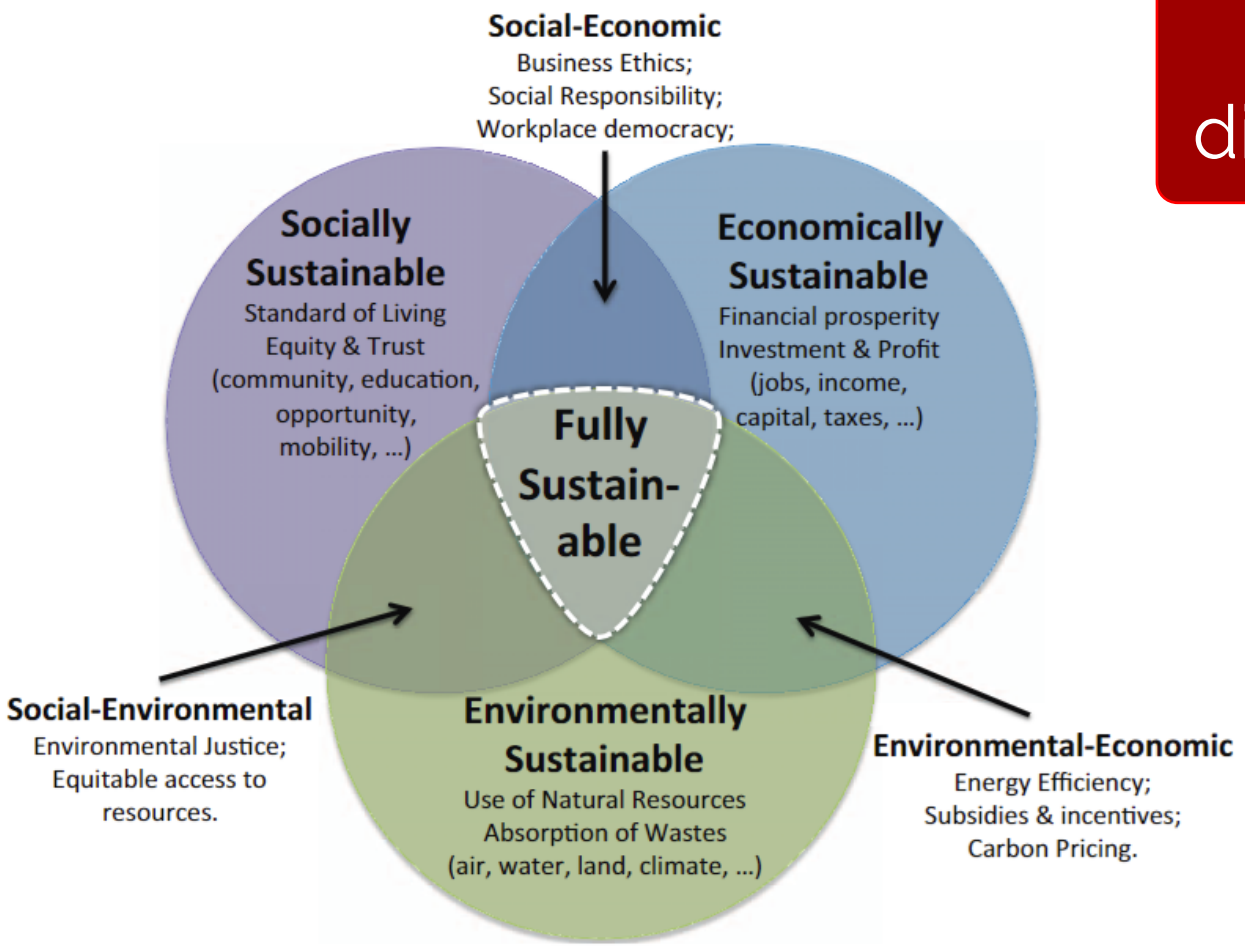
Data center emissions probably 662% higher than big tech claims. Can it keep up the ruse?

Emissions from in-house data centers of Google, Microsoft, Meta and Apple may be 7.62 times higher than official tally



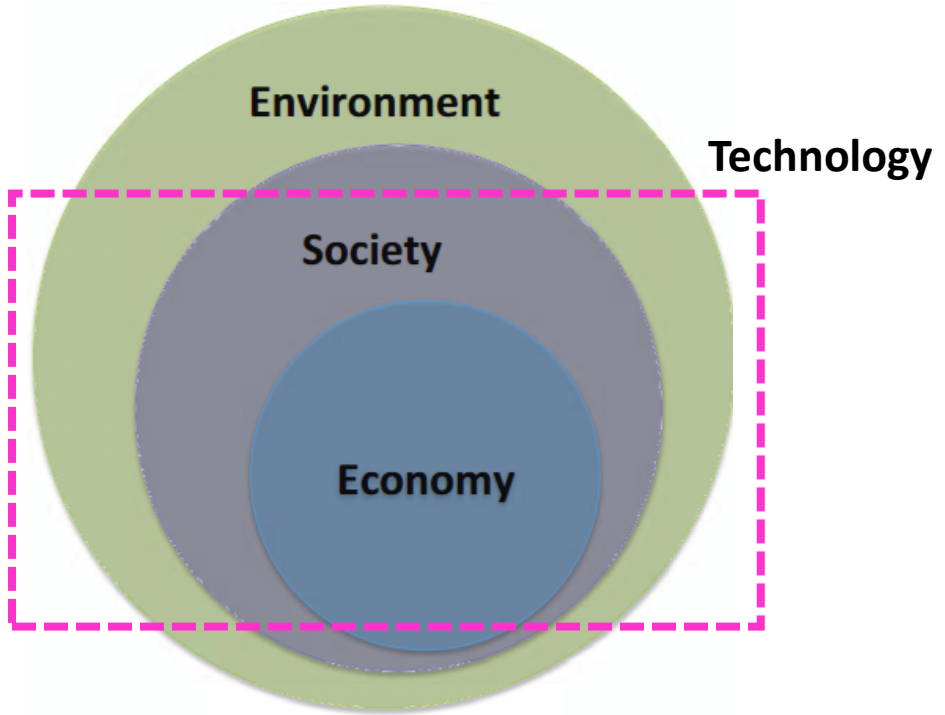
https://www.theguardian.com/technology/2024/sep/15/data-center-gas-emissions-tech

We need to **model** sustainability **in cooperation**

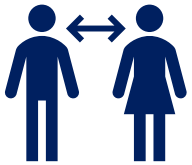


Weak notion of sustainability

Complexity → diverse expertise is needed



Strong notion of sustainability



Form of cooperation

Problems

Formalisms

Tools

Challenges&limitations

Form of cooperation

Cooperative modeling		Sustainability
"collaborative modeling" OR "participatory modeling"	AND	sustainable OR sustainability

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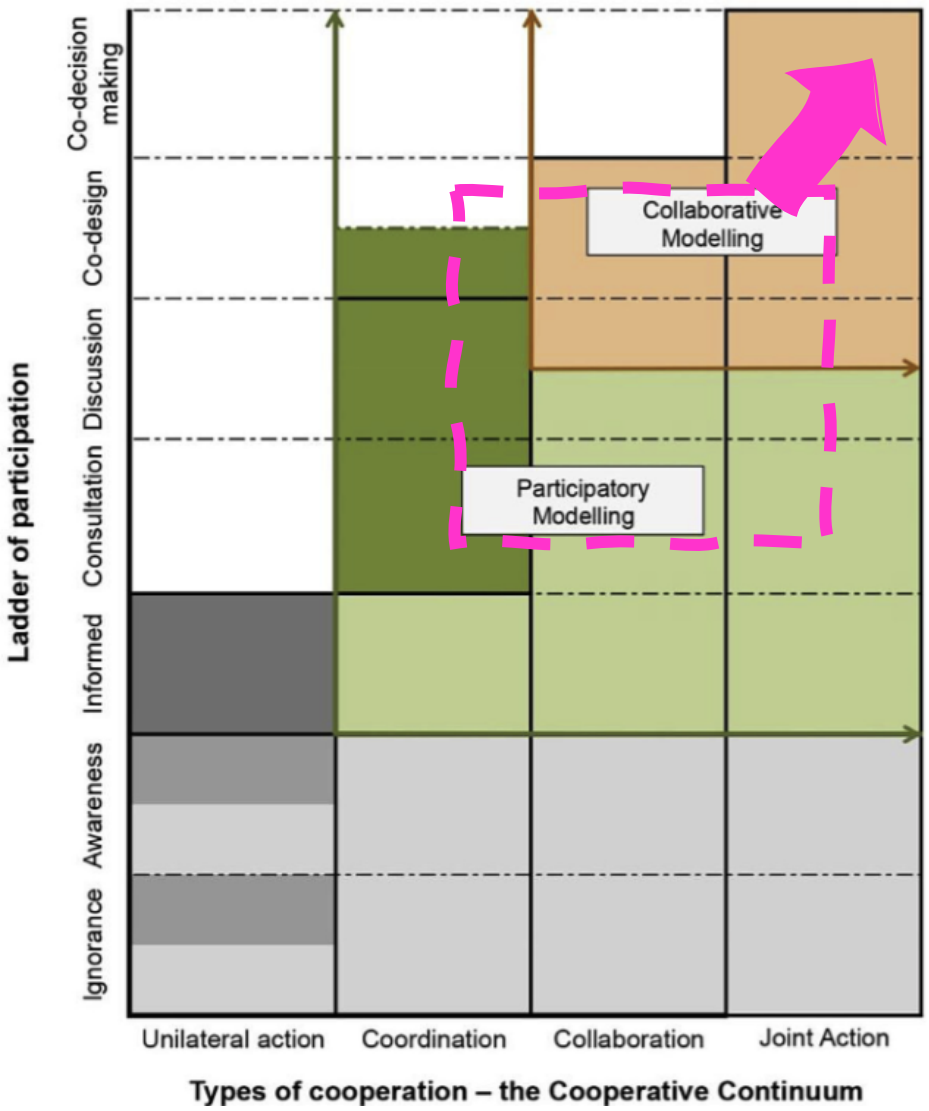
Table 5: Cooperation type

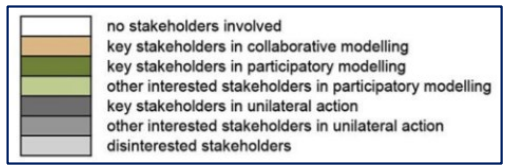
Coop. type	#Studies	Studies
Participatory	23 (95.8%)	[1–21, 23, 24]
Collaborative	1 (4.2%)	[22]

Table 6: Stakeholders

Stakeholder	#Studies	Studies
Domain expert	21 (87.5%)	[1–4, 6–21, 23]
Non-technical	19 (79.2%)	[1–9, 12, 13, 15–19, 22–24]
Technical	4 (16.7%)	[2, 7, 10, 18]

Combined CM+PM





Basco-Carrera et al. (2017) Collaborative modelling or participatory modelling? A framework for water resources management.

Transpose PM to collaborative modeling

- Stakeholder and communication aspects

Stakeholder types

Technical	28 (97%)	↘
Non-technical	11 (38%)	↑

- Motivating examples:
  - Narrating causal graphs with LLMs; completing reports for participants by generative AI; explanation generation by LLMs; DSLs…

Transpose collaborative modeling to PM

- Flexible model mgmt. and machinery
- Motivating examples
  - Model storage and retrieval, informal modeling languages, blended modeling

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Table 4: Support for sustainability dimensions

Dimension	#Studies	Studies
Environmental	22 (91.7%)	[1–15, 18–24]
Social	18 (75.0%)	[4, 6–20, 23, 24]
Economic	15 (62.5%)	[4, 5, 8, 10, 11, 13–20, 23, 24]

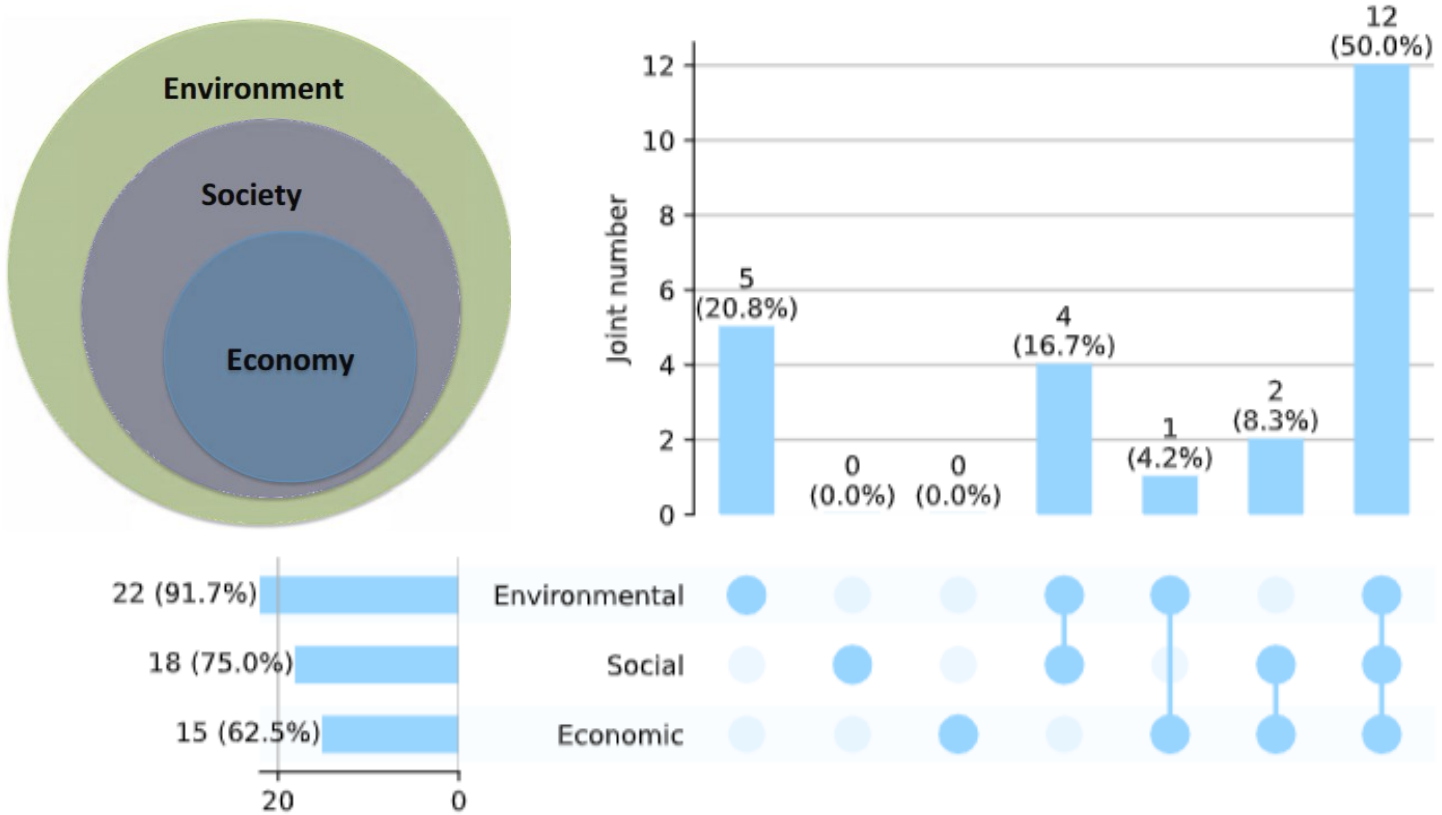

Figure 2: Breakdown of joint sustainability dimensions


Problems

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Challenges&limitations

Natural sciences–informed modeling

Problem

- Collaborative MDE: graph-based modeling semantics for SW
- Sustainability concerns:
  - Physics, biology, sociology, etc.
  - Continuous formalisms, non-linear relationships
  - Uncertainty (mostly epistemic)

What to build on?

- Integration of diverse modeling views by MPM, MVM, MLM

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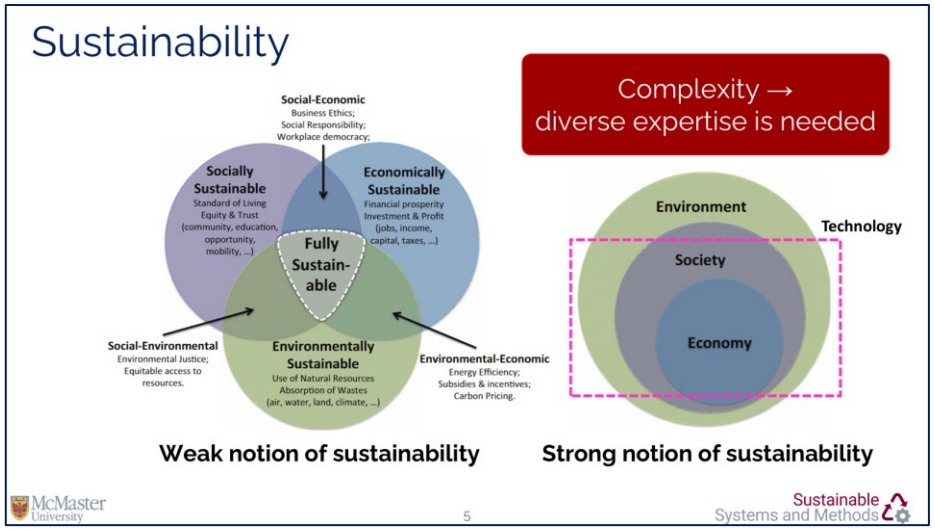
Systems evolution → technical sustainability

Problem

- Missing the context of evolution
- Sustainable design is impossible
  - Design for reuse, design for longevity, etc



What to build on?

- Systems evolution, model evolution, digital twin evolution…

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Table 9: Modeling formalisms

Formalism	#Studies	Studies
System Dynamics	12 (50.0%)	[1, 2, 4, 5, 8, 9, 14, 19–21, 23, 24]
Causal Loop Diagrams	11 (45.8%)	[1, 2, 4, 5, 7, 9, 13, 18, 20, 23, 24]
Bayesian Network	5 (20.8%)	[2, 3, 6, 10, 11]
Numeric Models	5 (20.8%)	[2, 11, 12, 14, 22]
Fuzzy Cognitive Map	3 (12.5%)	[15–17]
UML and others	3 (12.5%)	[4, 6, 12]

Table 10: Modeling intents

Modeling Formalism	#Studies	Studies
Quantitative simulation	15 (62.5%)	[1, 2, 4, 5, 11, 12, 14, 16, 17, 19–24]
Qualitative simulation	6 (25.0%)	[3, 4, 7, 9, 13, 18]
Other	4 (16.7%)	[6, 8, 10, 15]

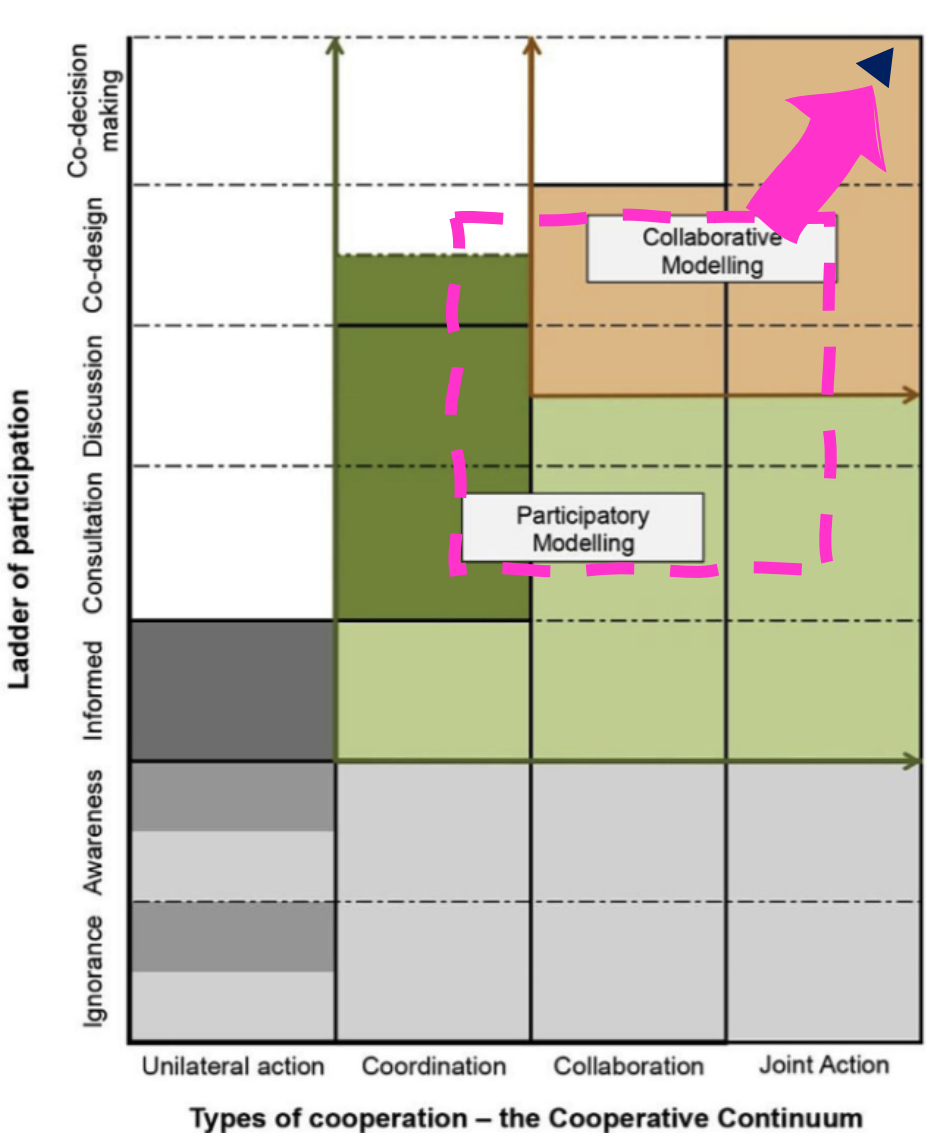
Multi-paradigm processes

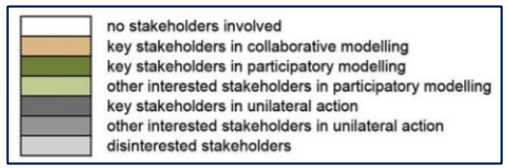
Problem

- Simulation tools/intents vs High-level formalisms
  - Detailed models are hard to devise
- Time-span: order of magnitude++

What to build on?

- Process modeling from business IS and MPM
- Strongly typed process formalisms, e.g., FTG+PM





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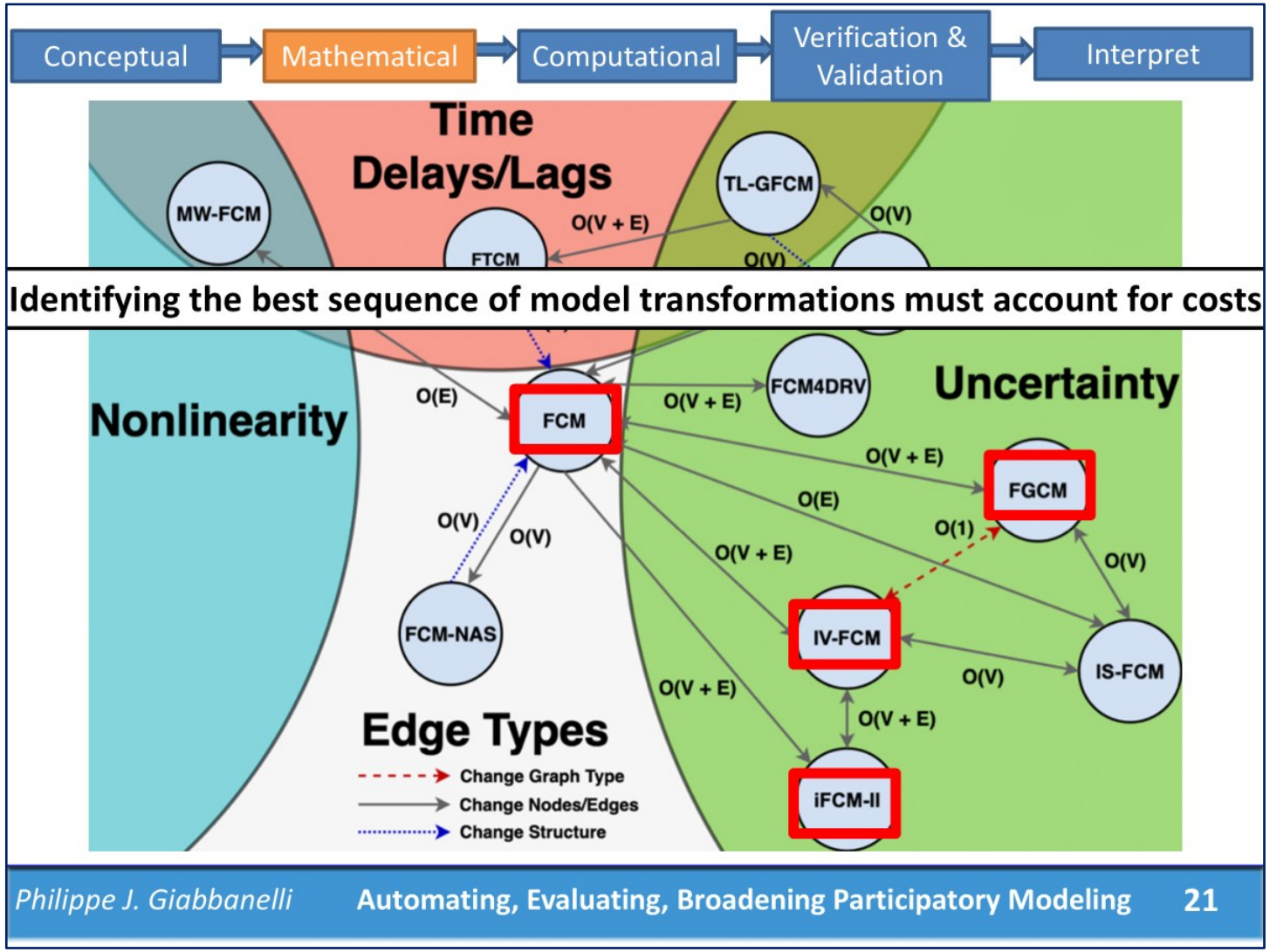

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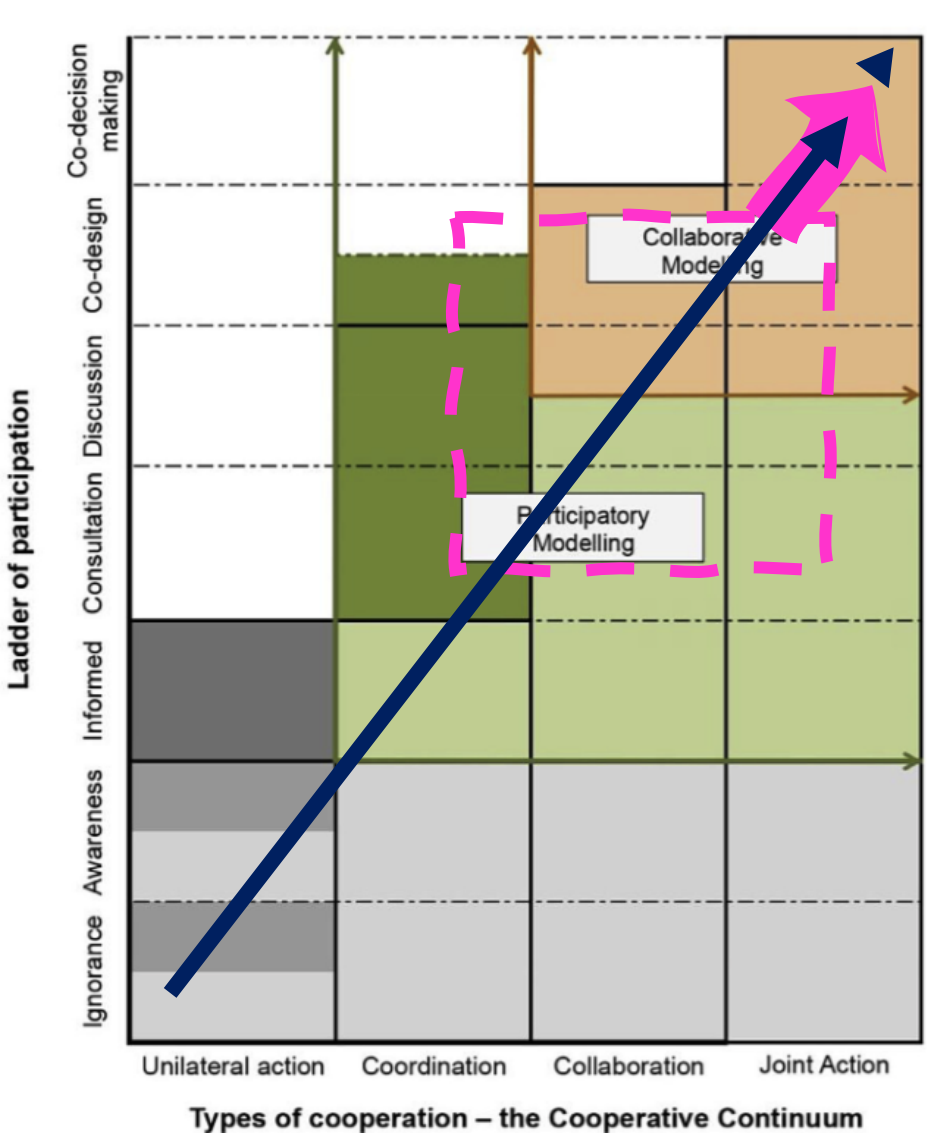

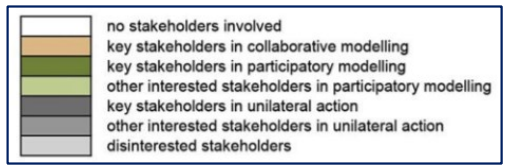

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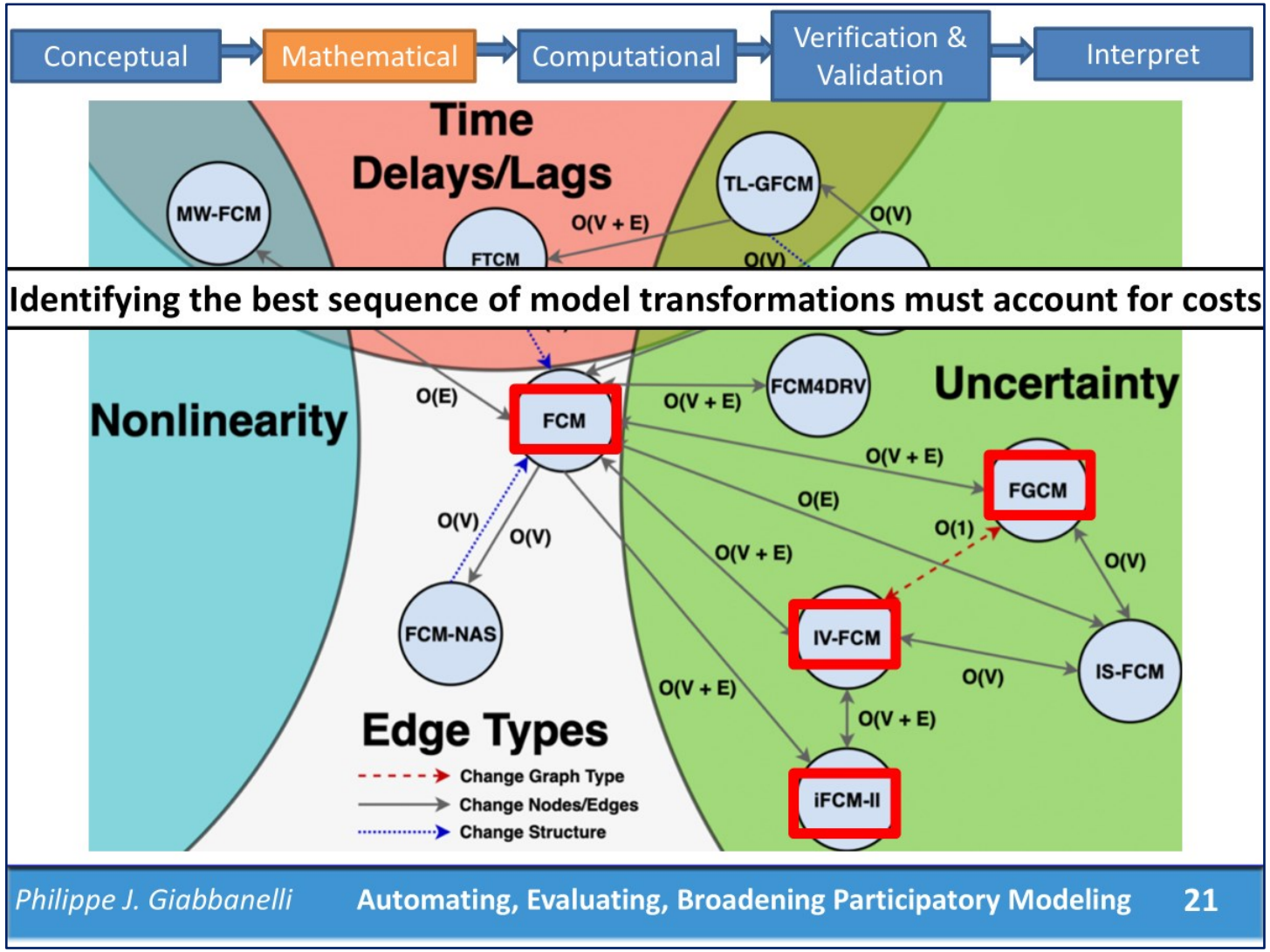

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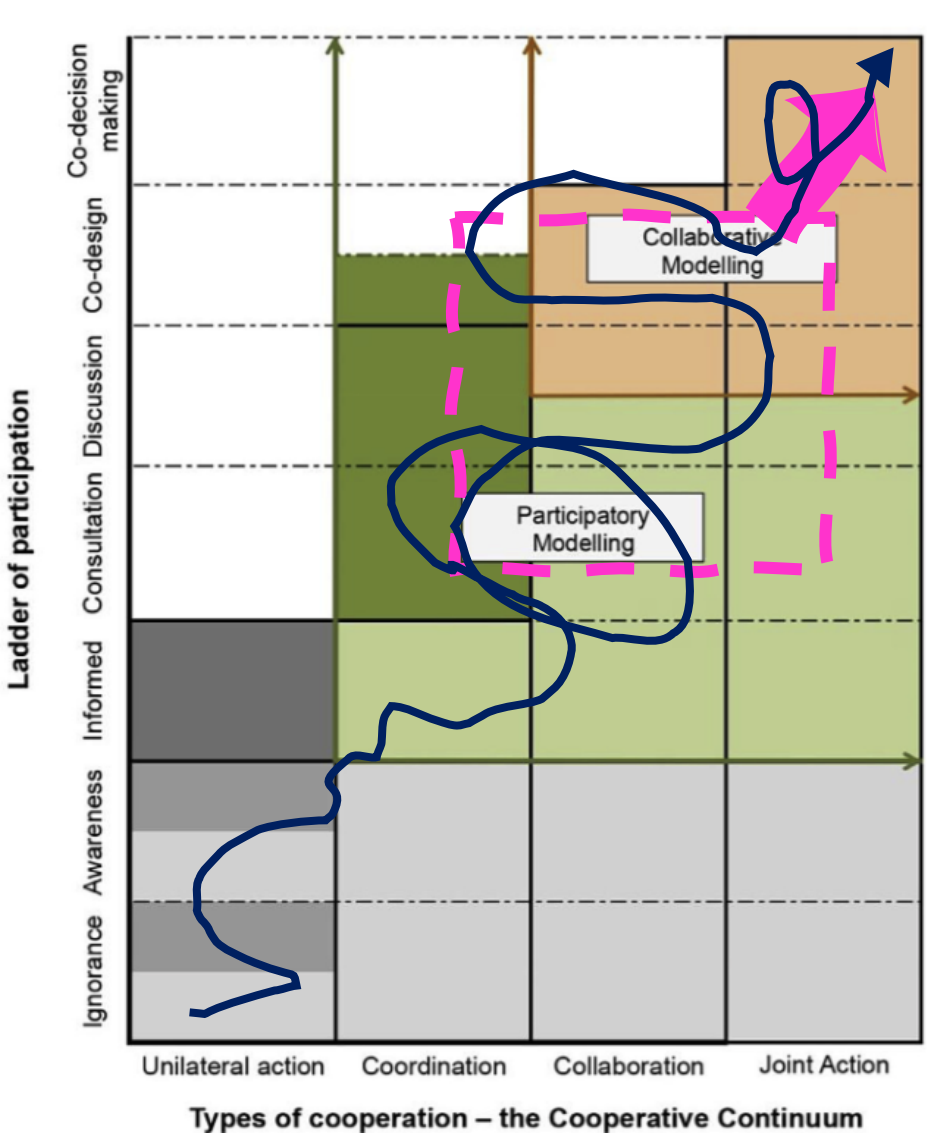

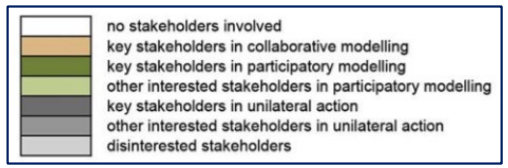

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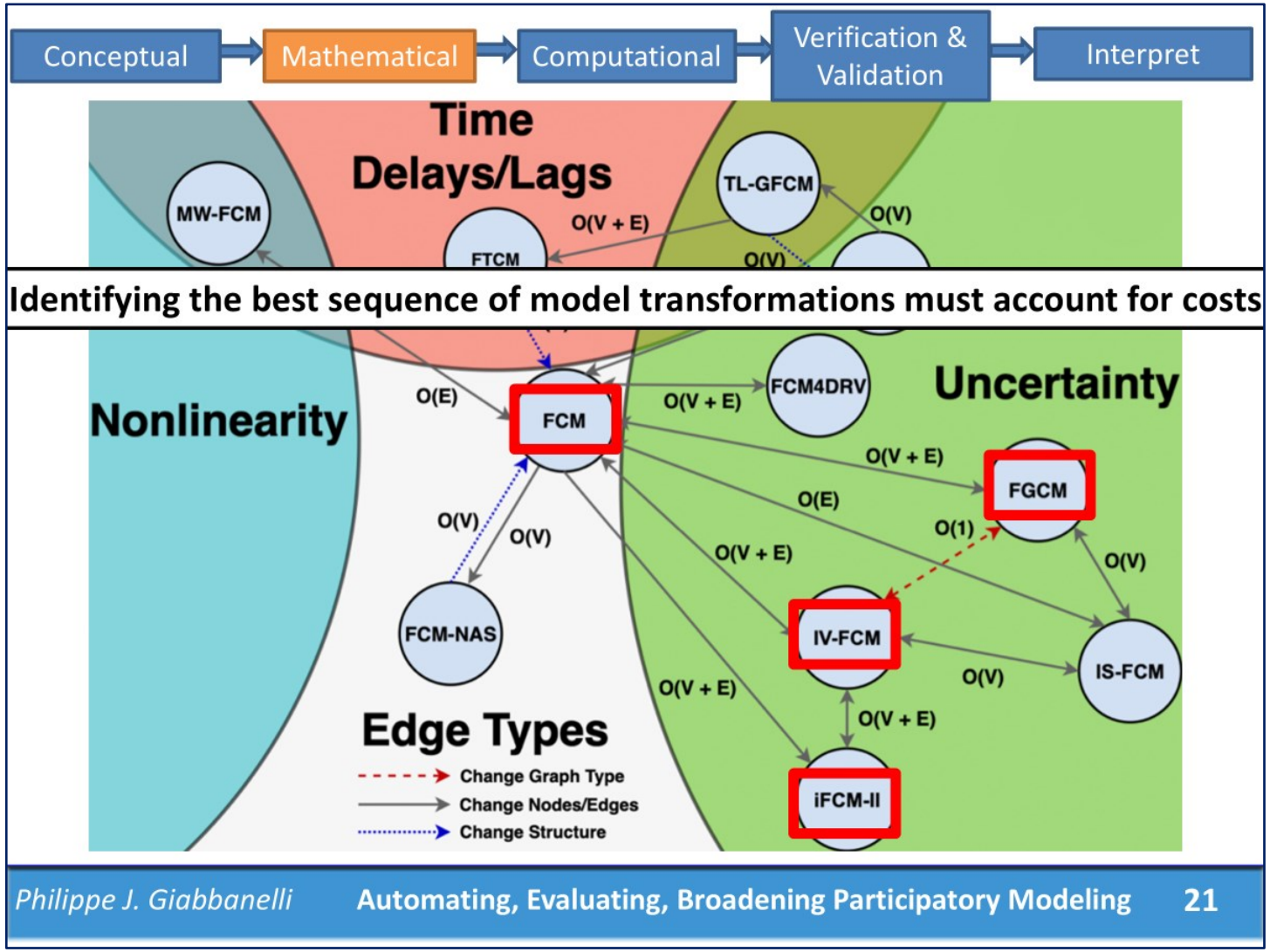

- Strongly typed process formalisms, e.g., FTG+PM

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Table 11: Type of tools

Type	#Studies	Studies
Simulation	22 (91.7%)	[1–7, 9–12, 14–24]
Drawing	2 (8.3%)	[8, 13]

Table 12: Type of tools by UI

UI	#Studies	Studies
Mixed	17 (70.8%)	[2, 4, 5, 7–10, 12, 14–19, 21, 23, 24]
Visual	6 (25.0%)	[1, 3, 6, 11, 13, 20]
Textual	1 (4.2%)	[22]

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Complex modeled phenomena

- Uncertainty, lack of causality
- Lack of empirical data

Act of modeling

- Methods and techniques
  - Conceptual modeling: often insufficient
  - Refining high-level models to detailed ones
  - Optimization for opposing goals
- Humans
  - Diversity/interdisciplinarity is essential
  - Lack of qualified stakeholders
  - Scalability of cooperation

Socio-political context

- Government action is needed
- Lack of appropriate financial frameworks

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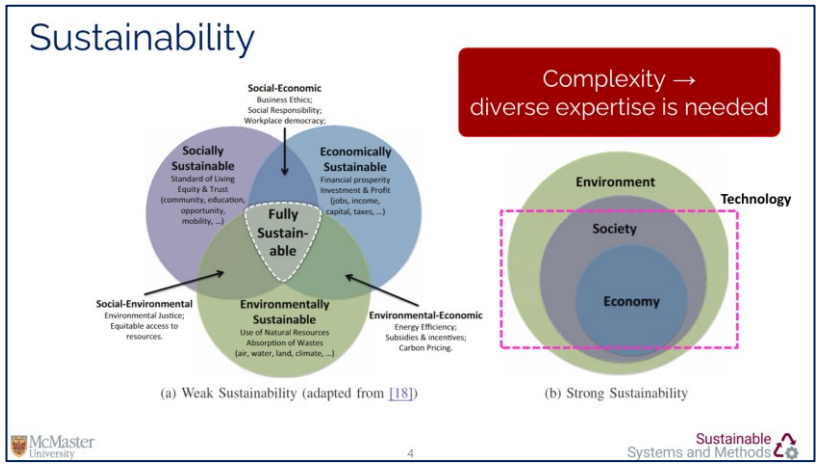

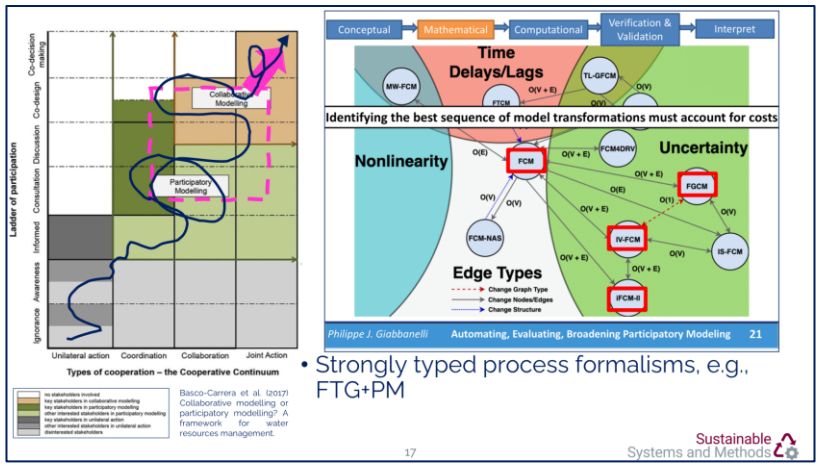

Form of cooperation — Almost exclusively participatory modeling

Problems — Convoluted problems, environmental focus

Formalisms — High-level formalisms

Tools — Simulation tools

Challenges & limitations — Actionability, vertical refinements, etc