Civil Engineering
University of Toronto

Digital Twins and the Realization of Green Interactive Buildings

Prof. Tamer E. El-Diraby, PhD., PEng.

Coordinator, Intelligent Buildings Digital Twin Center
Dept. of Civil & Mineral Engineering
University of Toronto

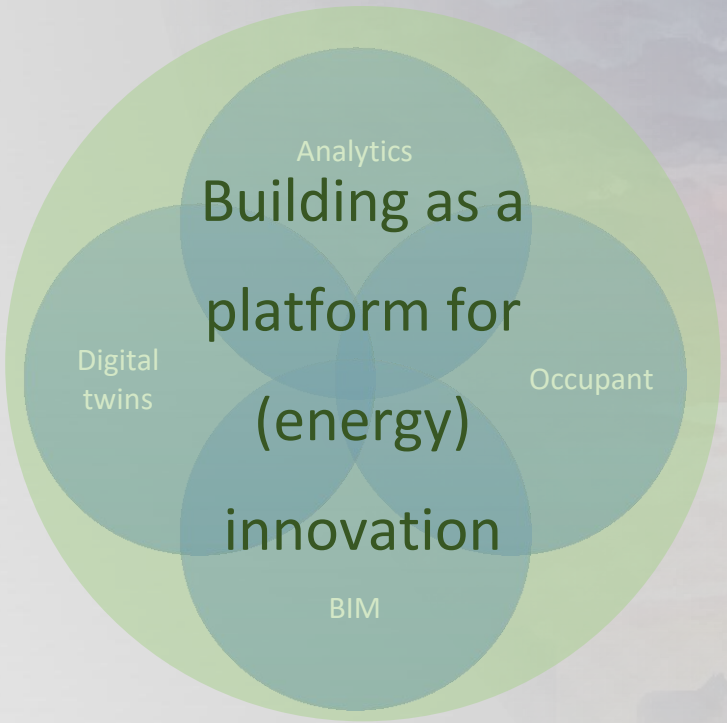
Agenda

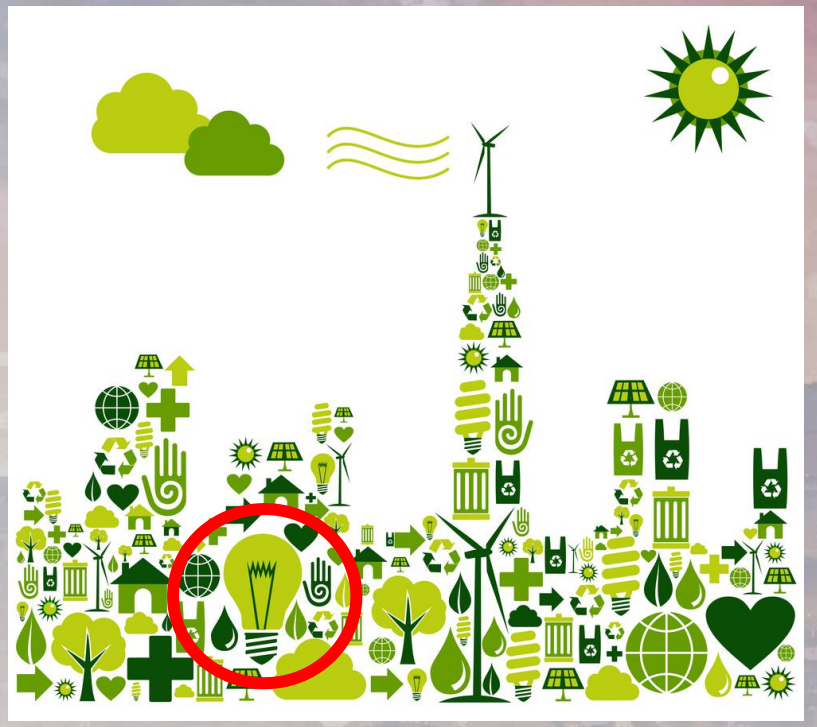
- From Green to regenerative sustainability
- Defining digital twins

- UofT digital twin design
- BIM-based Green analytics: demo
- Future plans

Summary

- Can greening buildings be a driver for the economy?
- Can greening buildings be a driver for the economy through innovation?

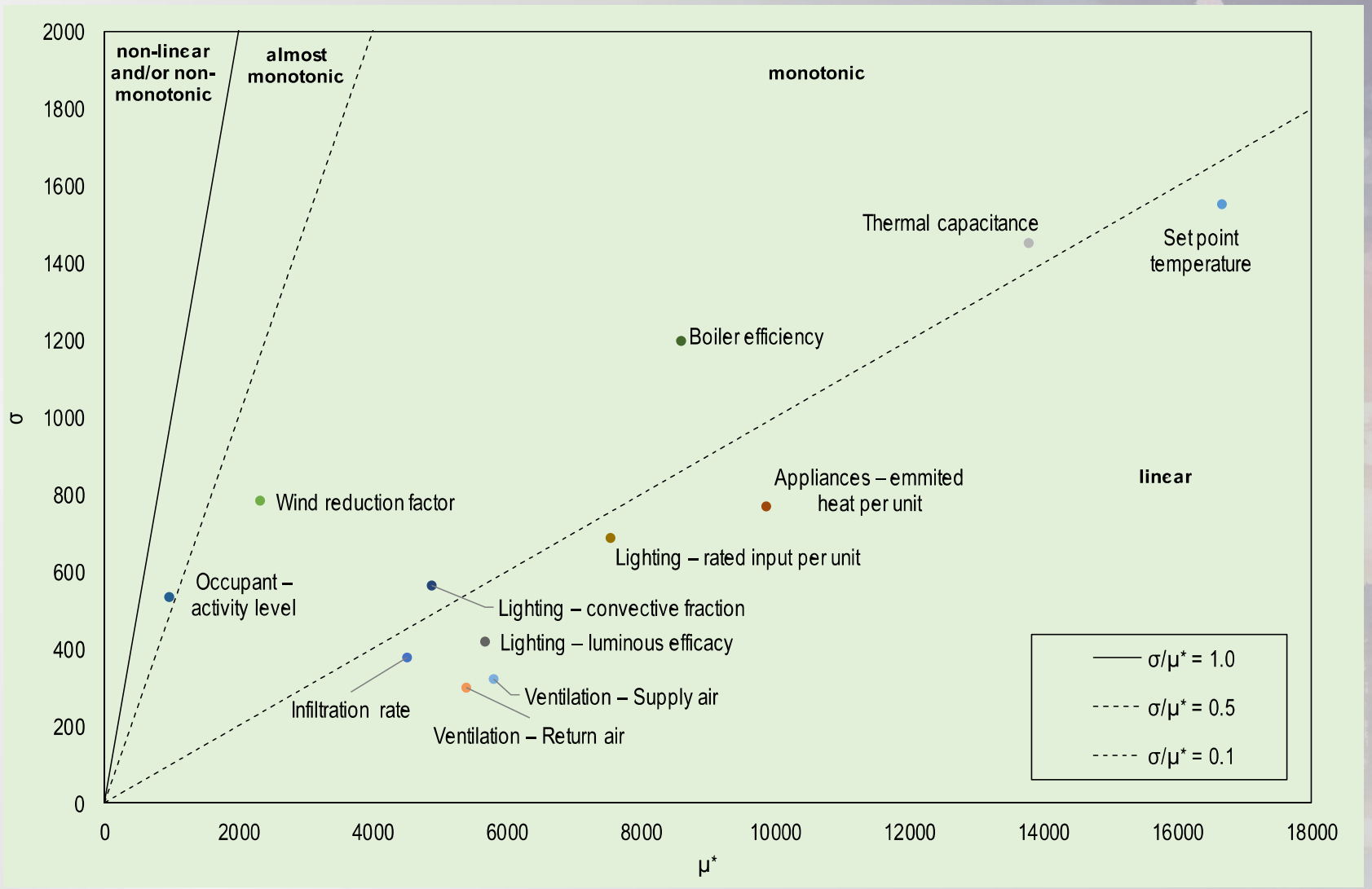




- Objective: How to overcome the difficulty of green analysis, throughout the life cycle, to help operators and users to transfer greening their facility into economic and business benefits?


Regenerative sustainability

People behavior matters



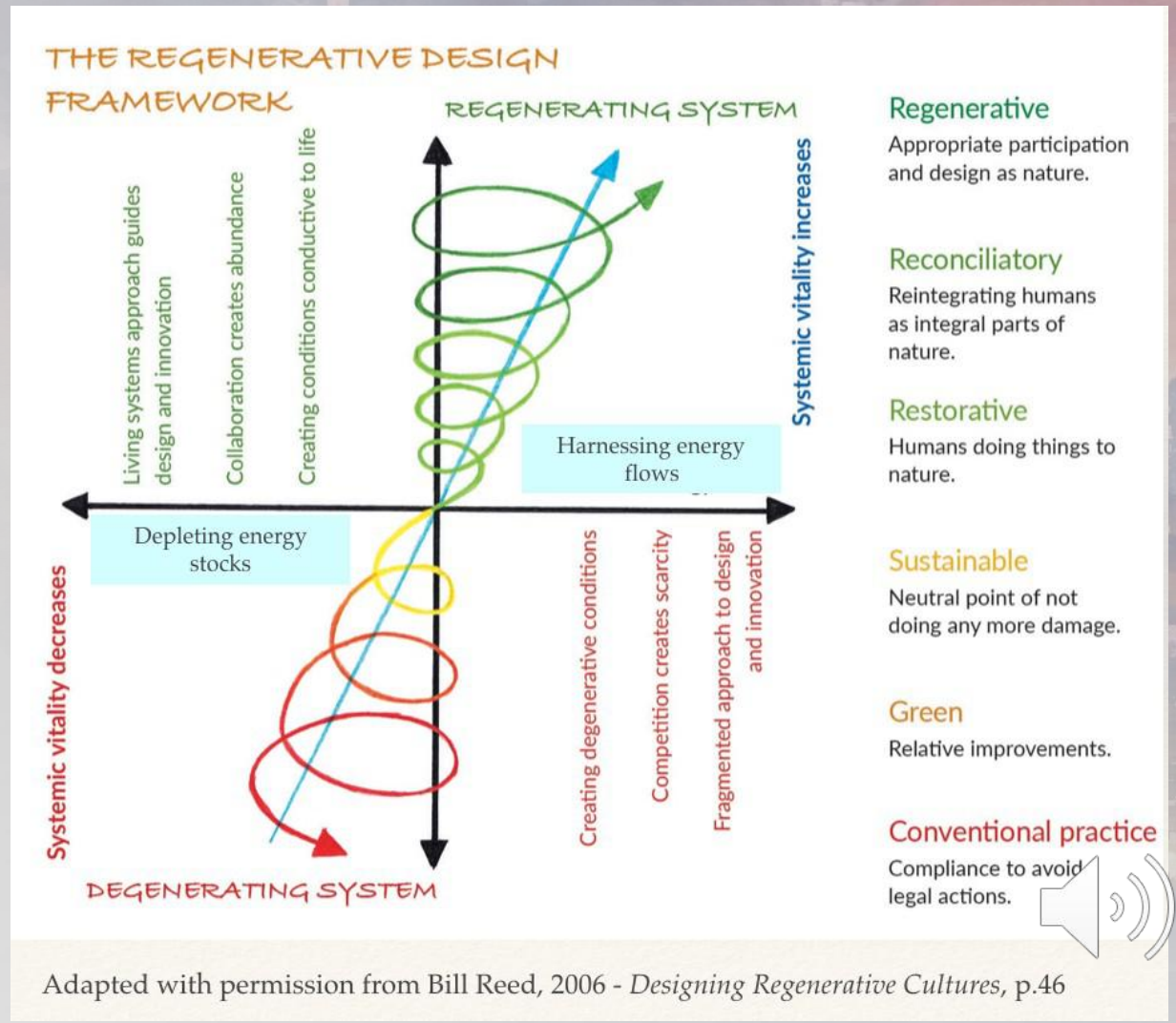
Stegnar, G., & Cerovšek, T. (2019). Information needs for progressive BIM methodology supporting the holistic energy renovation of office buildings. *Energy*, *173*, 317-331.

Regenerative sustainability

Creating conditions for:

- Harnessing energy flows
- Support design as nature
- Empower people to innovate
- Green as the driver for economy

- Building to re-generate natural sys.



Adapted with permission from Bill Reed, 2006 - *Designing Regenerative Cultures*, p.46

Reed, B. (2007). Shifting from 'sustainability'to regeneration. *Building Research & Information*, *35*(6), 674-680.

BIM & green buildings

Why BIM is needed for Green Buildings

- BIM based design enables in-depth assessment of energy performance
- BIM offers knowledge- based decisions for renovation strategies and quality control.
- BIM enhances the design and project management of green buildings
  - better management of project requirements and capacity to manage building information
  - better communication between project stakeholders
  - improved decision making enabled by multiple design options - alternatives in the early project stages
  - interdisciplinary coordination and validation, and analysis leading to effective collaboration,

The problems of BIM in green building analysis

- Extensive modelling and processing of captured data into se- mantic BIM objects is required;
- Demanding information up-dates of pre-existing BIM models and databases are needed; and
- Data about the objects and relationships that are actually located and used in buildings is unreliable.

Barki H, Fadli F, Shaat A, Boguslawski P, Mahdjoubi L. BIM models generation
27.from 2D CAD drawings and 3D scans: an analysis of challenges

Not just design data

- Engineering calculations/Technical models (e.g. thermal analysis/energy audits);
- Simulations (e.g. usage scenarios);
  statistical methods (e.g. performance);
- Machine learning (e.g. patterns and trends);

Criteria	Indicator	Sub-Criteria
Indoor comfort	Indoor air quality	Occupancy-based ventilation rates
		CO2 concentration above outdoor level
		Subjective reaction as classification of the indoor air quality
		Occurrence of Radon gas*
	Lighting comfort	Lighting properties
		Luminaire intensity
		Upwards light
		Luminance
	Thermal comfort	Operative temperature
		Radiant temperature asymmetry
		Floor temperature
		Draught, air velocity
		Humidity in indoor air
Energy efficiency	Reduction of energy consumption	Heating
		Hot water system
		Cooling
		Cold water system
		Air-conditioning
		Ventilation
		Lighting
		Fans
		Pumps and controls
		Electrical equipment
	Energy generation	
	Energy monitoring	
	Energy efficiency saving	
Water efficiency	Water consumption	
Pollution	CO2 emissions	
	Construction waste	
	Cradle to cradle consideration	

Borgstein EH, Lamberts R, Hensen JLM. Evaluating energy performance in non-domestic buildings: a review. Energy Build Sep 2016;128:734–55.

Stegnar, G., & Cerovšek, T. (2019). Information needs for progressive BIM methodology supporting the holistic energy renovation of office buildings. *Energy*, 173, 317-331.

The problem: limitations of IFC & linked data

- Interactive linkage between BIM and energy analysis systems
- Semantics
- Capture of unstructured data

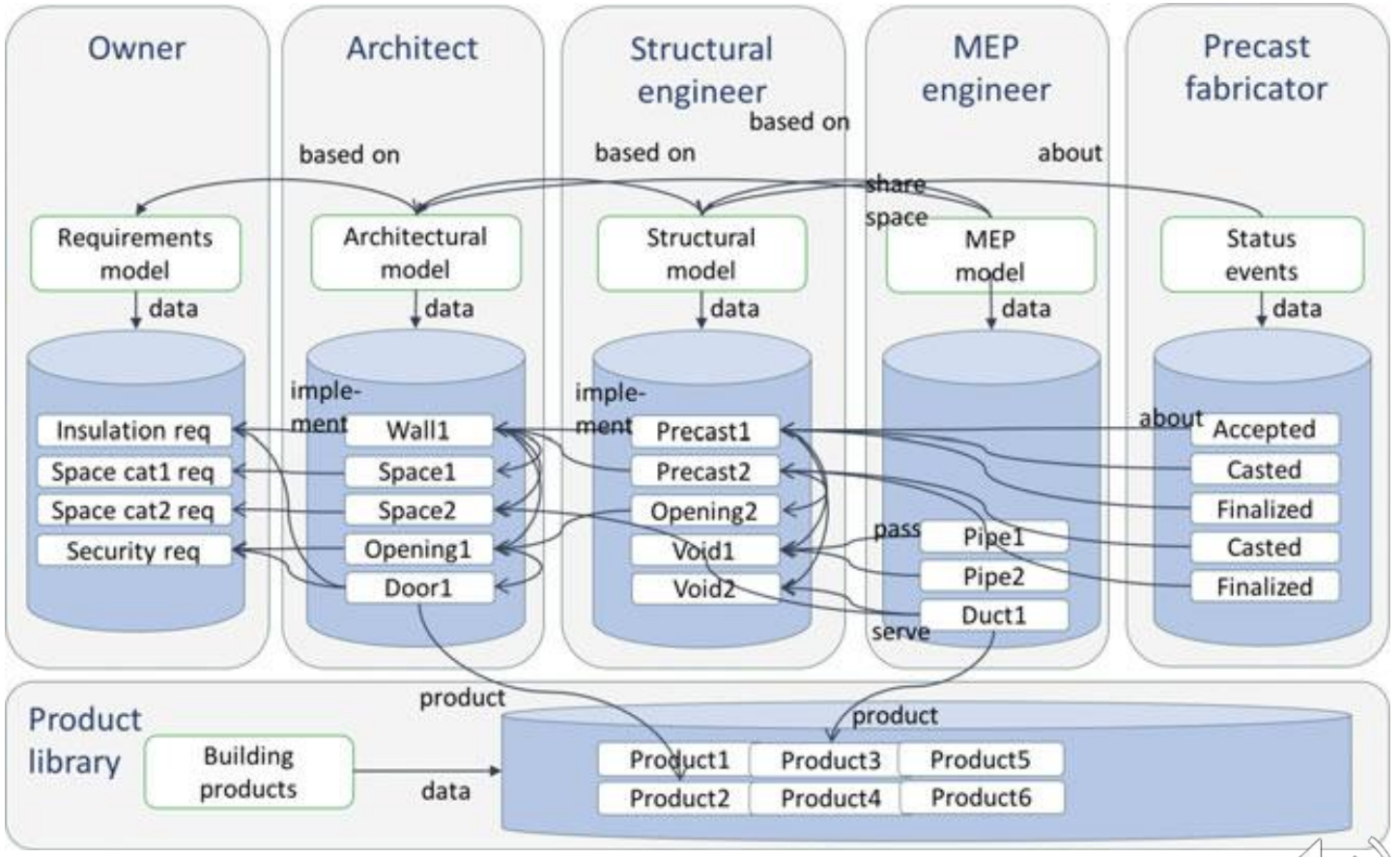


Fig. 10.6 Interlinked models using specialized relationships (implements, serves, spatial overlaps). (© S. Törmä, reprinted with permission)

Borrmann, A., König, M., Koch, C., & Beetz, J. (2018). Building Information Modeling Technology Foundations and Industry Practice: Technology Foundations and Industry Practice.


Digital twins

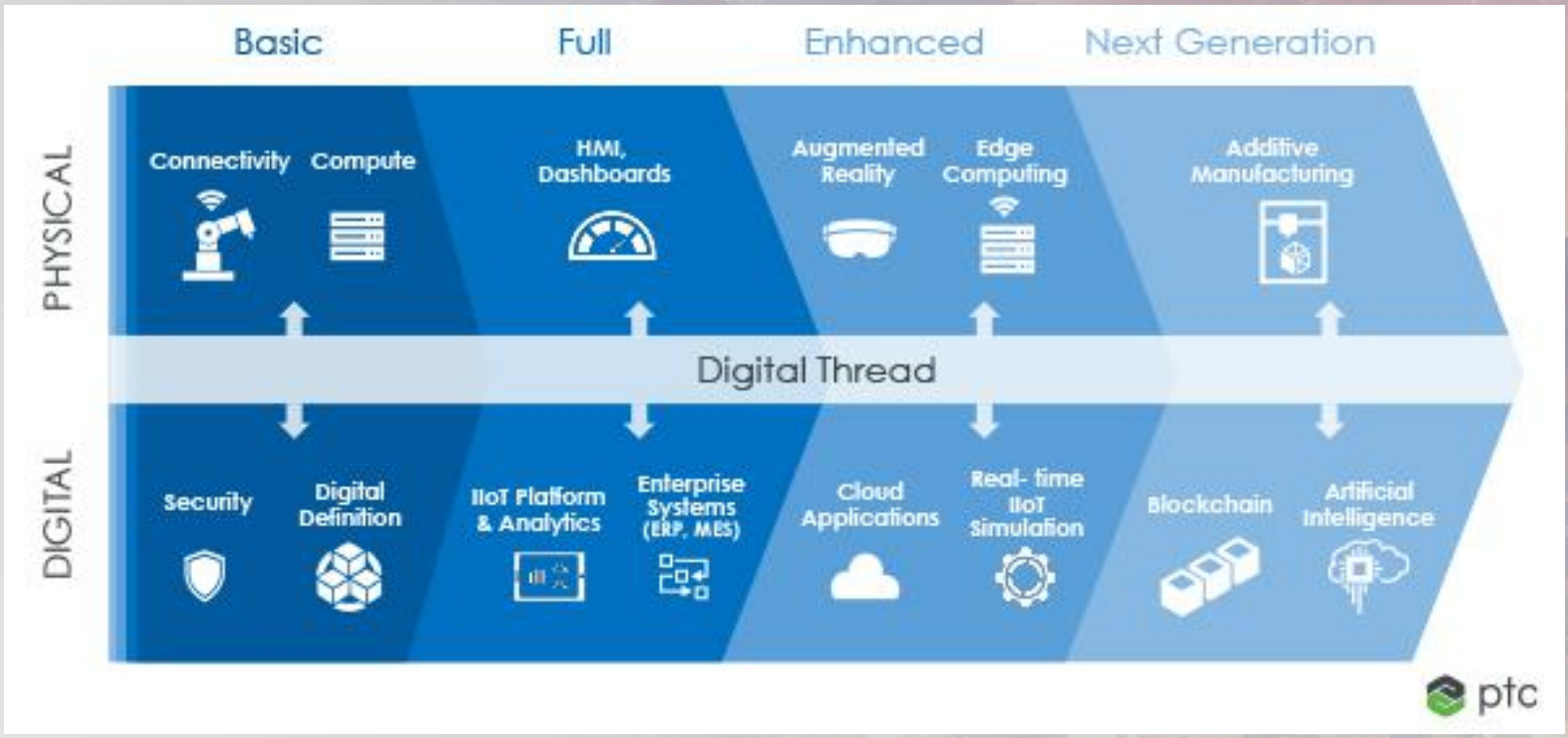
A Bad of Digital Twins

- Digital twining is different from digitization
- Digital twining is not virtual reality

A Typical (product) view of digital twins

This view is missing the following:

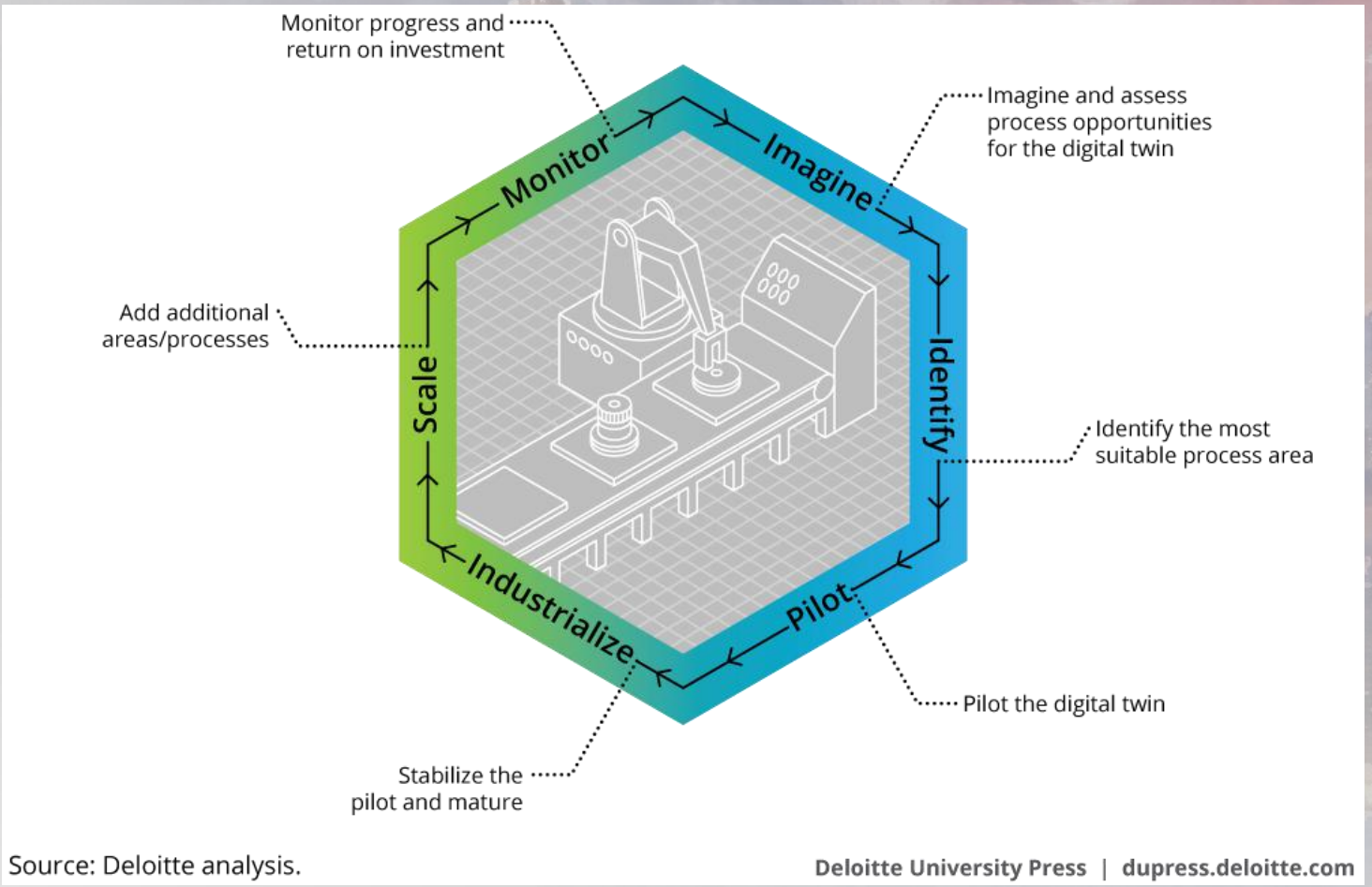
- Asset management
- Occupant empowerment
- Data governance



The Evolution of Digital Twin – and How Emerging Tech Is Driving Adoption
Written By: David Immerman

Types of digital twin

- Product digital twin
- Predictive twin
- Process twin
  - Examining alternative designs
  - Re-designing the digital twin



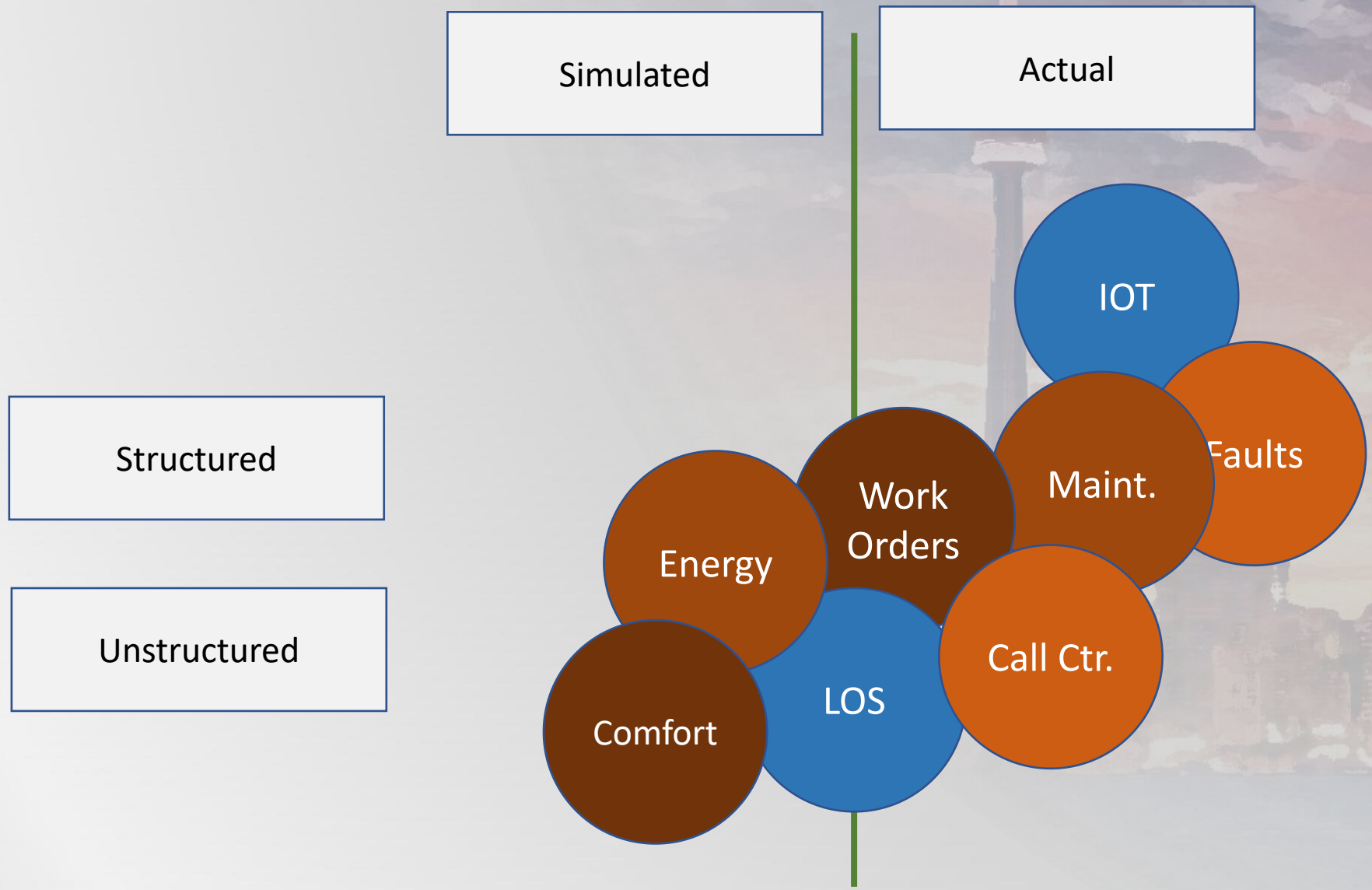
DT & RS : when green is the economic driver

- **Data**
  - Facility data
  - Operational data
  - Occupant data
- **Futures and simulations**
  - Energy models
  - Operational schemes
  - Analytics
- **Business intelligence**
  - User profiling
  - Predictive analytics
- **People empowerment**
  - Innovation
  - New green business models

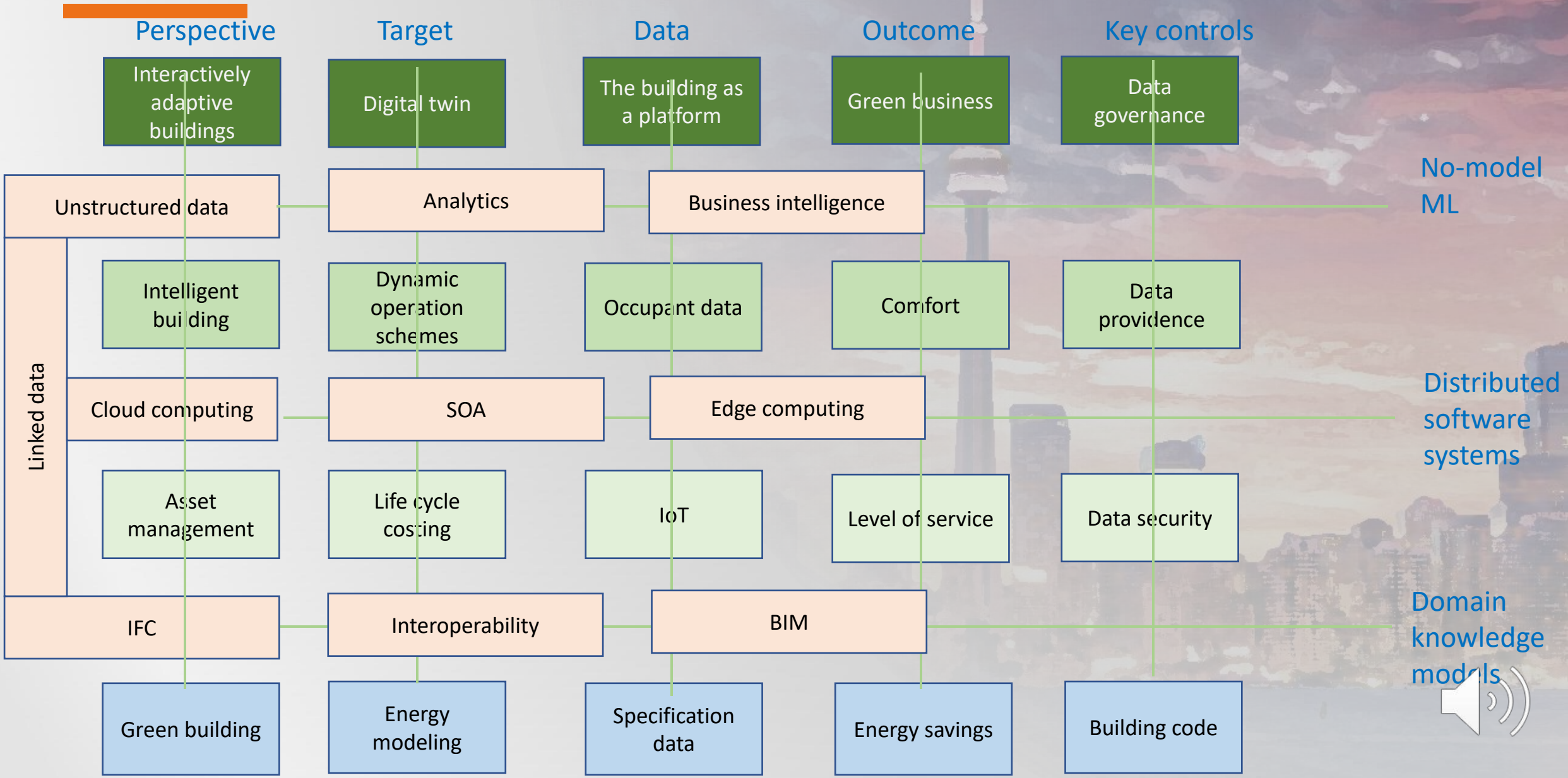
Image credit: Keith Shaw and Josh Fruhlinger: What is a digital twin and why it's important to IoT
Network World | JAN 31, 2019


The UofT
Intelligent Building Digital Twin

Digital twins and facility management



A perspective on digital twins



Digital twin project scope

Data Security

Access
Recovery

Governance

Usage rights & ethics
Algorithmic operations

Empowerment

Co-creation
Citizen innovation

Data reliability

Data providence
Data cleaning

Machine learning

Soft sensing
Predictive analysis

	Un-structured Data	Structured Data
Building Data	Maintenance logs Work orders Schedules	IoT BIM Energy
Contextual Data	Conditions Access User profile	Weather

UofT Facility Management Staff

Pahse 1: Interactive floor plans & reports
Phase 2: Data reliability & interoperability
Phase 3: Business intelligence

Digital Twin

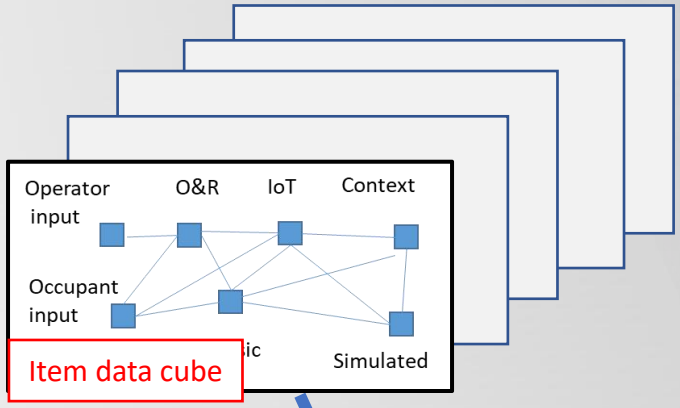
Building Stakeholders

Phase 1: access for researchers
Phase 2: access to occupants
Phase 3: building-as-a-platform

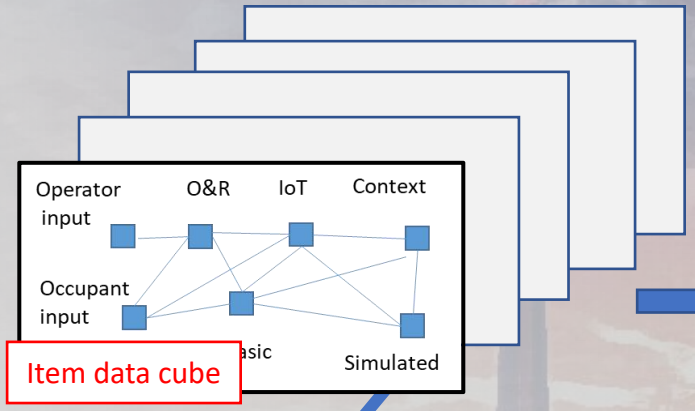
Interactive BIM systems

Cross-item analytics of data

Cross-building analytics of items and data



Item data cube

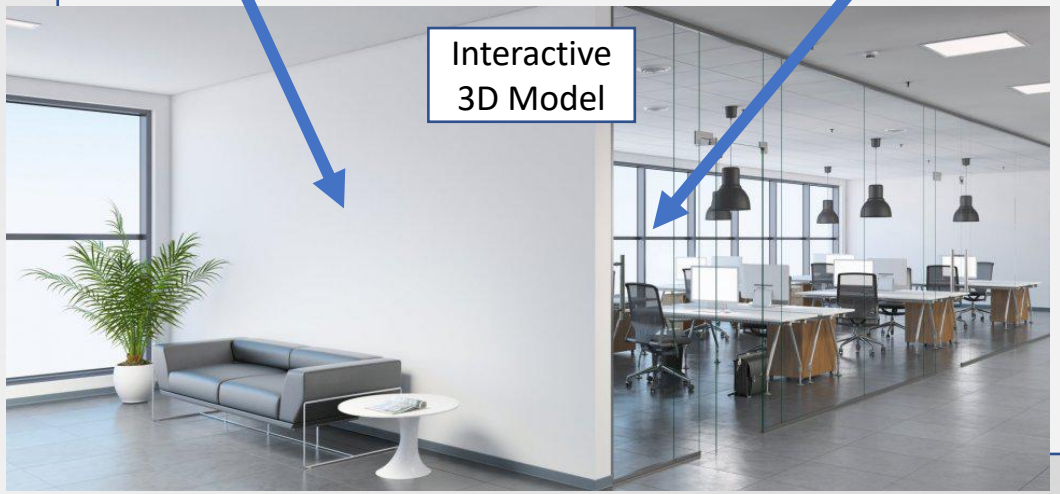


Item data cube

Access rights

Usage patterns

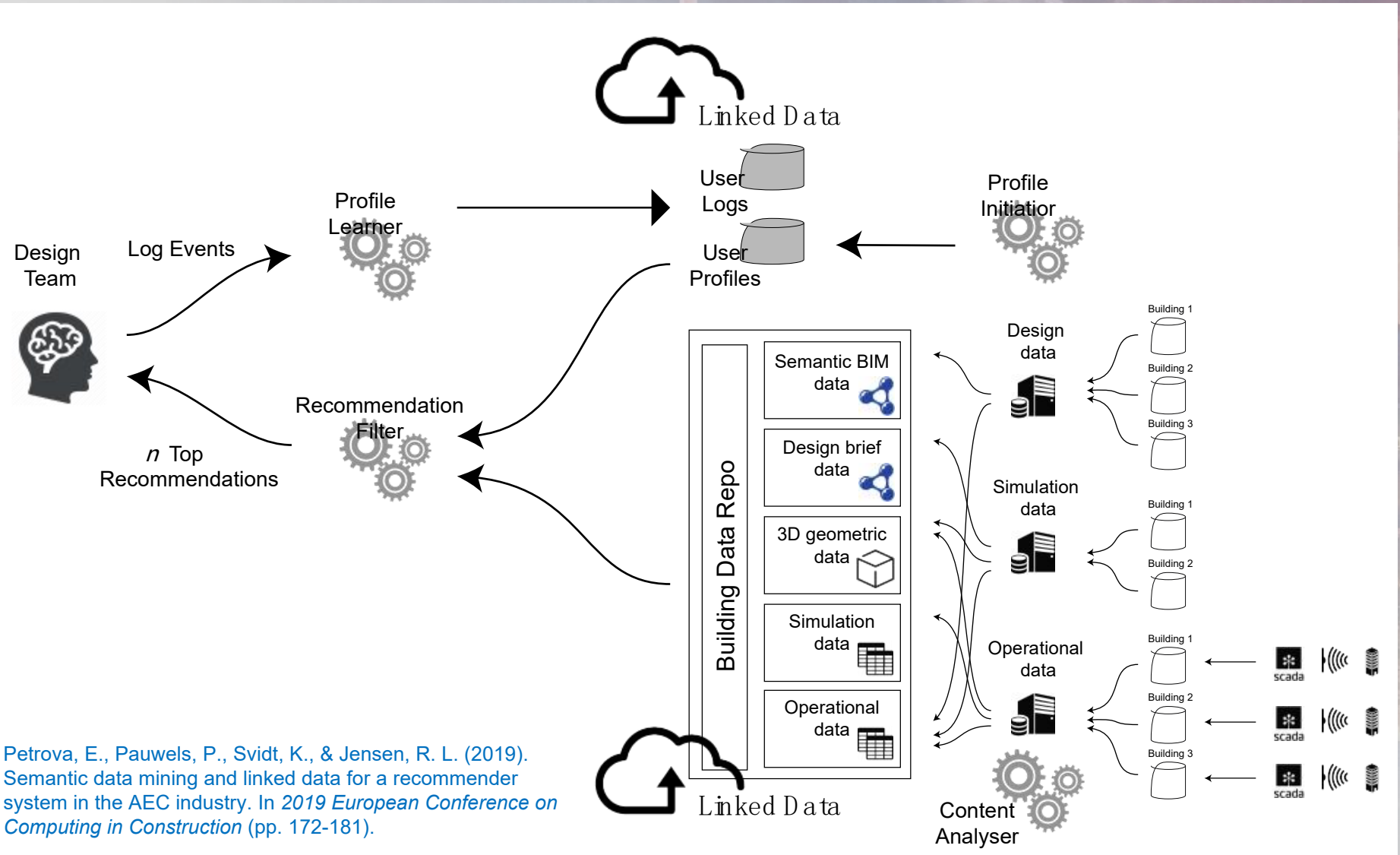
Interactive 3D Model



Machine learning in intelligent buildings

- The modeling issue: BIM should encompass all building data
- The linkage issue: BIM data is not limited to IFC

- The analysis issues: No generic reasoning and querying.
- Complexity: a challenge to



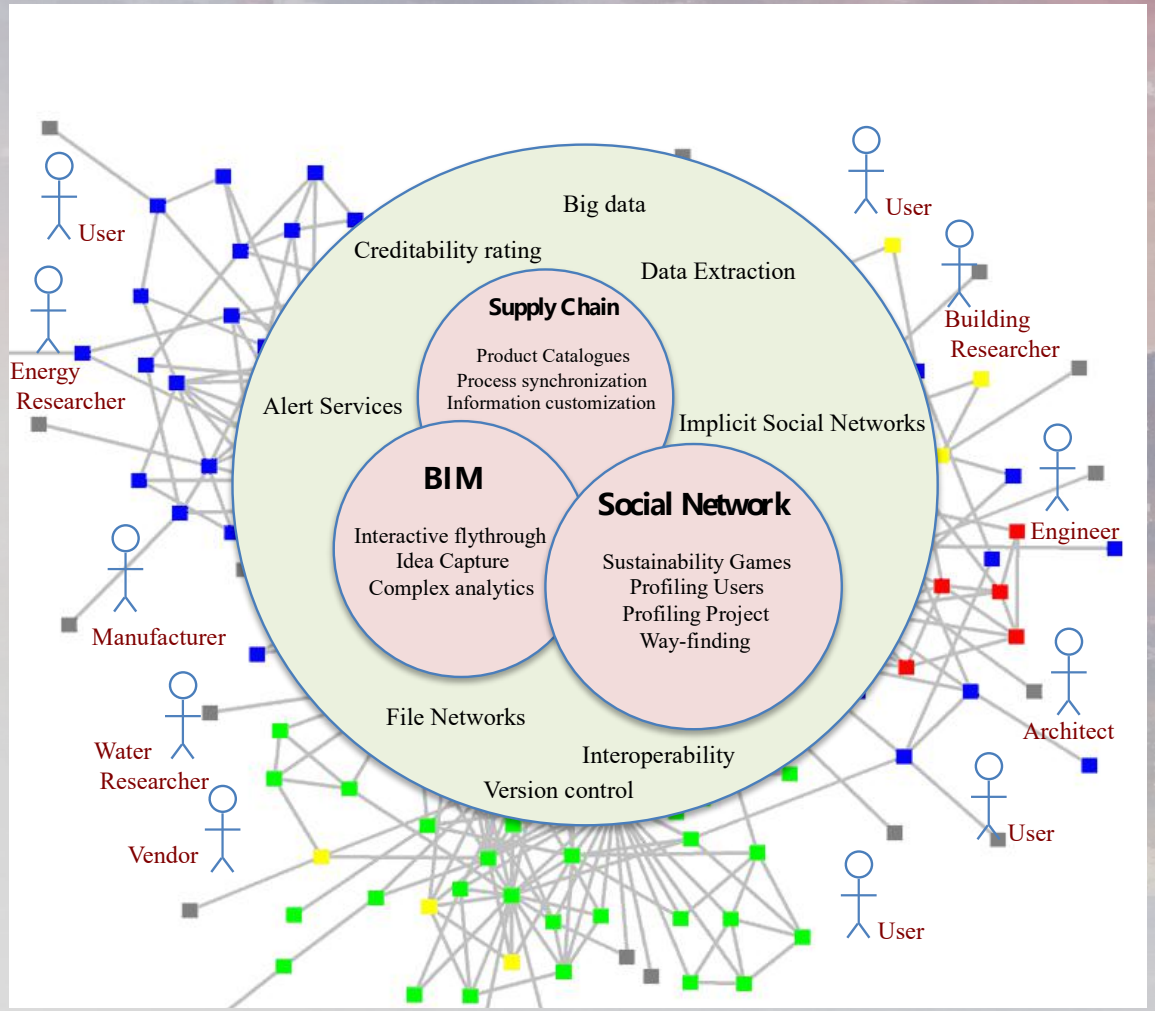
Petrova, E., Pauwels, P., Svidt, K., & Jensen, R. L. (2019). Semantic data mining and linked data for a recommender system in the AEC industry. In *2019 European Conference on Computing in Construction* (pp. 172-181).


Green 2.0

Conceptualization: mixing structured and unstructured data

To realize interactive intelligent buildings, we need a green supply chain of material, information, and ideas:

- BIM: data access, visualization
- User: profiling, social & semantic networks
- Designers: optimal design features
- Operators: adaptive operations schemes



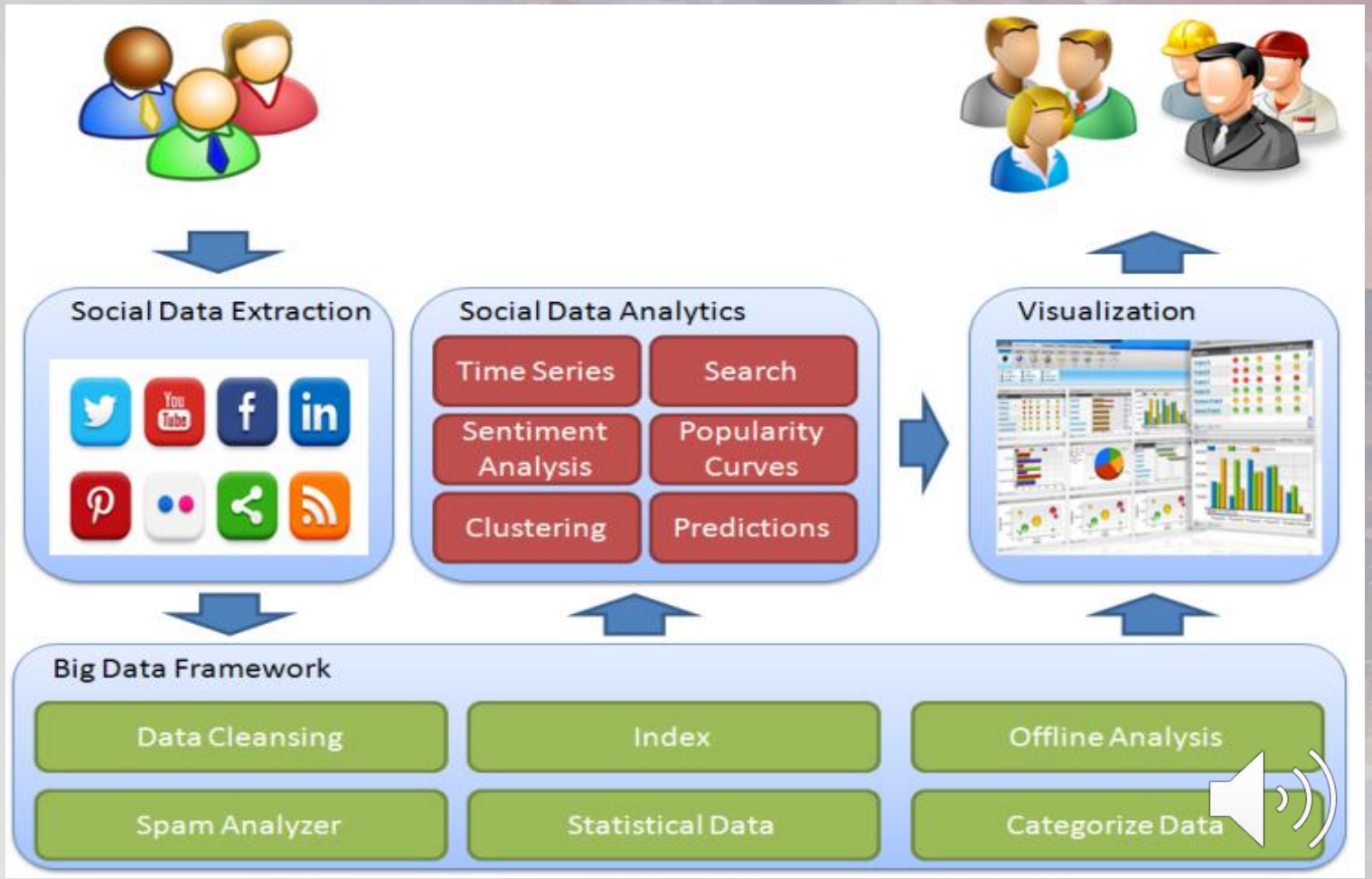
The Requirements

Interaction

- Users navigate the BIM Model, explore, learn and comment
- Designers, contractors do the same
- All contribute data, ideas, needs, apps.

Machine learning

- Analyze the chat and extract the needs, learn about the opportunities, exchange knowledge
- Find synergies, discover overlaps, and synchronize business processes



Green 2.0

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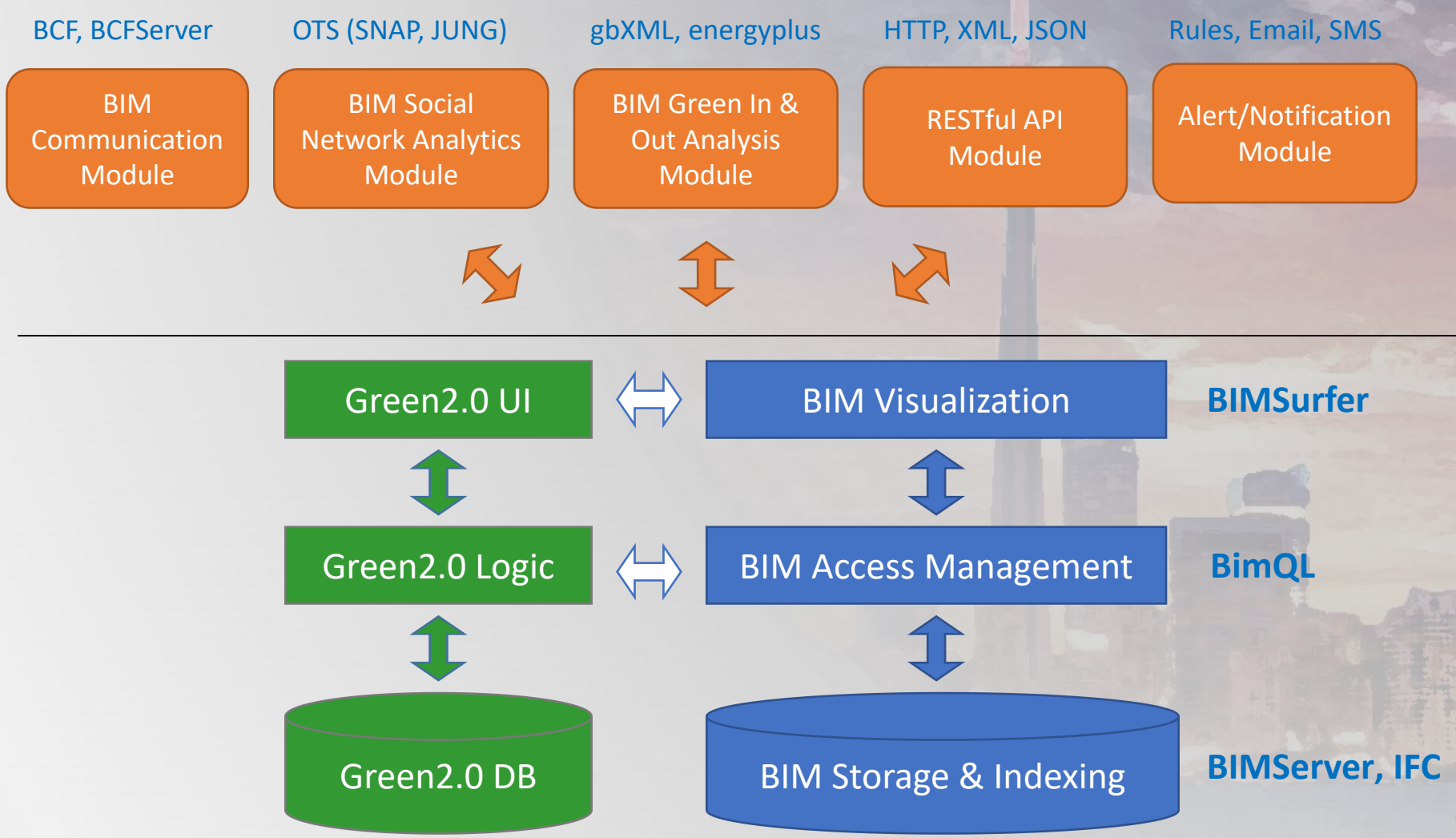
Green 2.0

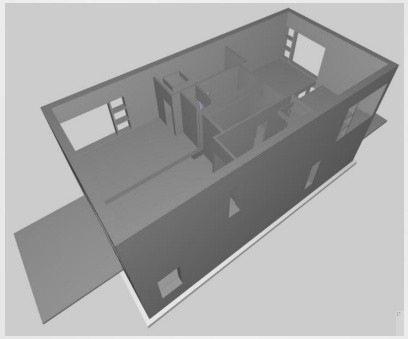
The technical architecture

Open platform



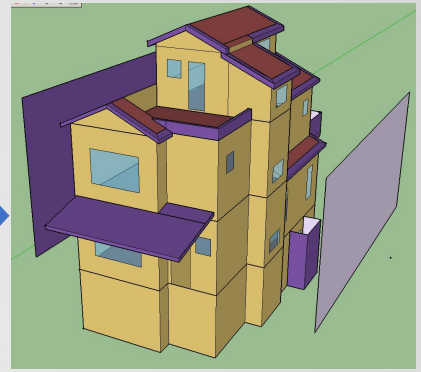
Linking BIM to energy analysis: IFC to OpenStudio

IFC Compatible



In a **BIM model** a building is described as a **decomposition** of building elements with individual **solid** representations

OpenStudio Compatible

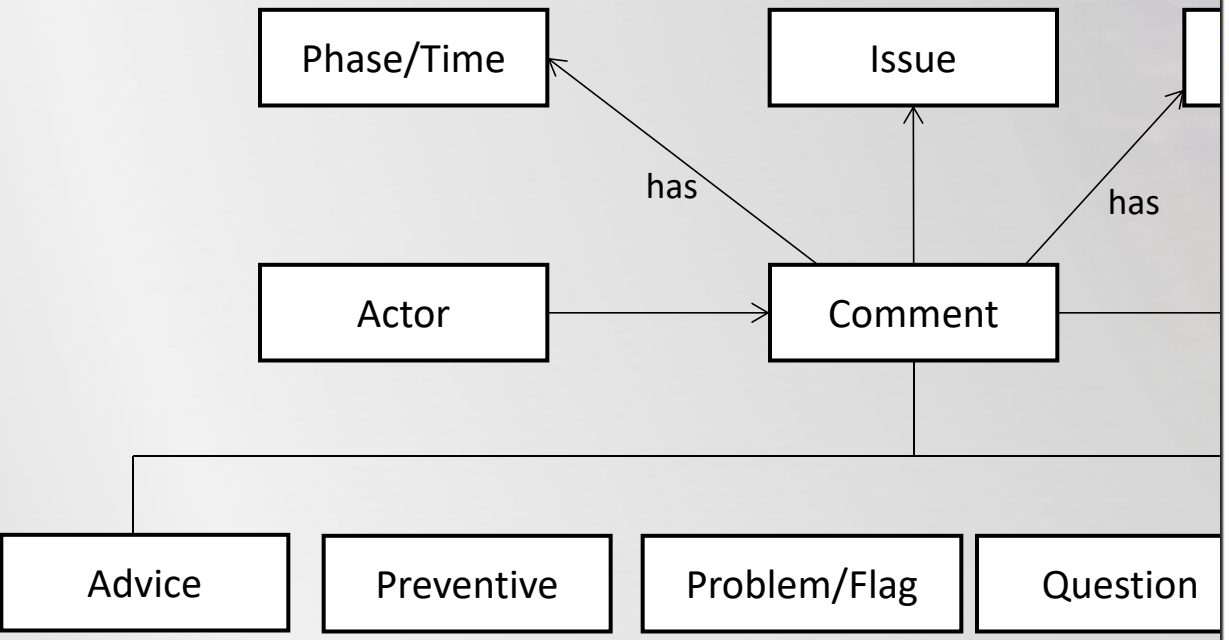


For energy analysis geometry needs to be aggregated into **'water-tight' 'thin-walled' thermal zones**

Algorithm 1 Collapse solid wall volumes

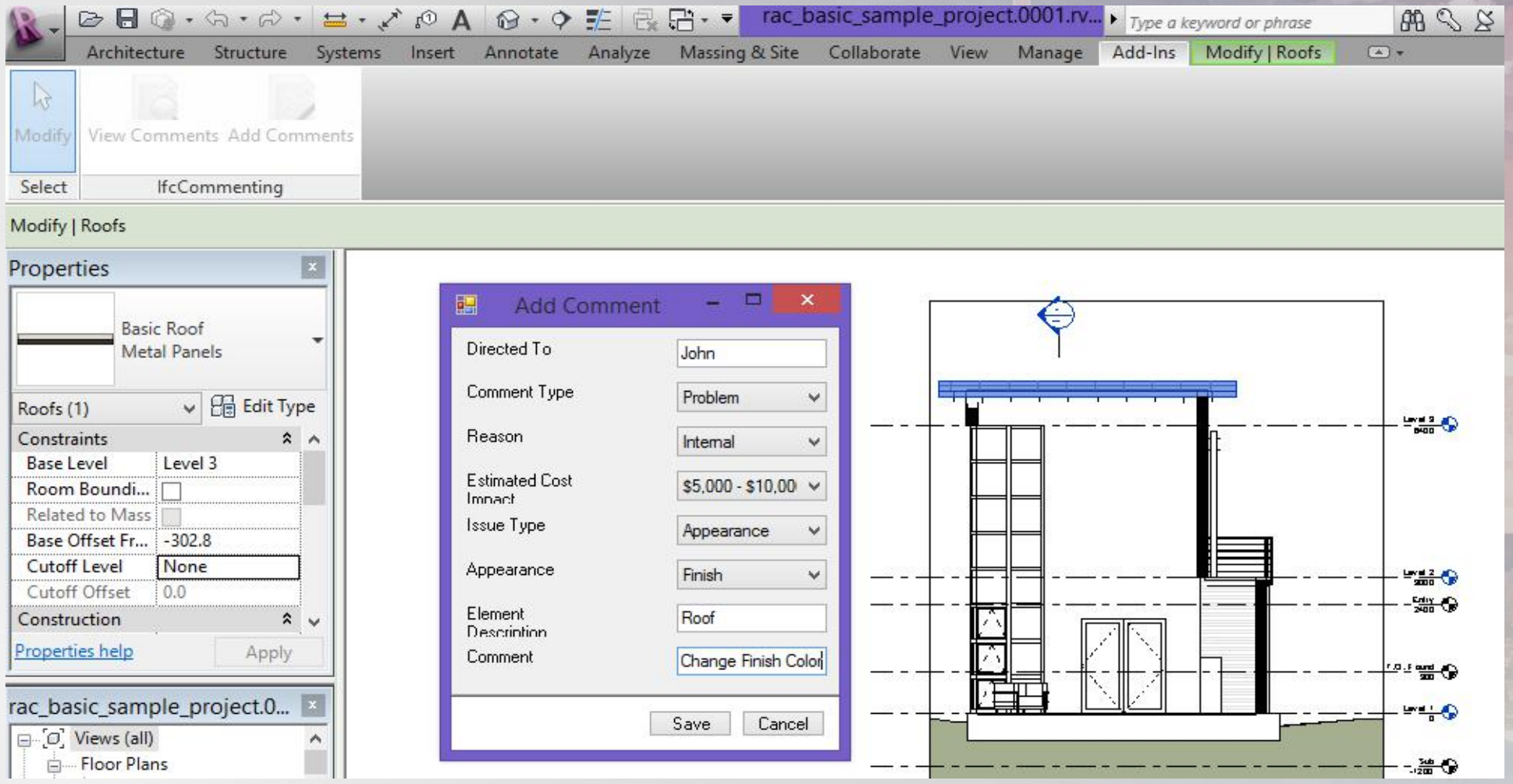
```
1:  function COLLAPSE(w)
2:      for all rep in w.Representation.Representations do
3:          if rep.RepresentationIdentifier ="Axis" then
4:              A_w ← BREP(rep)                          ▷ Create Boundary Representation
5:          else if rep.RepresentationIdentifier ="Body" then
6:              B_w ← BREP(rep)
7:      assert EDGES(A_w) ≠ ∅
8:      assert FACES(B_w) ≠ ∅
9:      C_Aw ← CURVE(e) | e ∈ EDGES(A_w)                 ▷ Random edge from set,
                                                          wall assumed continuous
10:     d ← ∅
11:     u ← (∞, −∞)
12:     for all F_Bw in FACES(B_w) do
13:         if SURFACE(F_Bw) ∥ P_XY then                 ▷ Parallel with XY plane
14:             if SURFACE(F_Bw) ∩ C_Aw ≠ ∅ then         ▷ Intersects with axis curve
15:                 for all V_FBw in VERTICES(F_Bw) do
16:                     P_0 ← POINT(V_FBw)
17:                     u_0 ← PROJECT(P_0 → C_Aw)        ▷ Project point onto
                                                          axis curve, returns
                                                          curve parameter
18:                     u ← (min(u(0), u_0), max(u(1), u_0))
19:                     P_1 ← C_Aw(u_0)                  ▷ Evaluate curve at u_0
20:                     v⃗ ← P_1 − P_0                    ▷ Find difference vector
21:                     d = d ∪ v⃗                        ▷ Add to set
22:     assert |d| = 2                                   ▷ Modulo modeling precision
23:     return EXTRUDE(TRIM(OFFSET(C_Aw → avg(d)), u))
```

A model of the comment

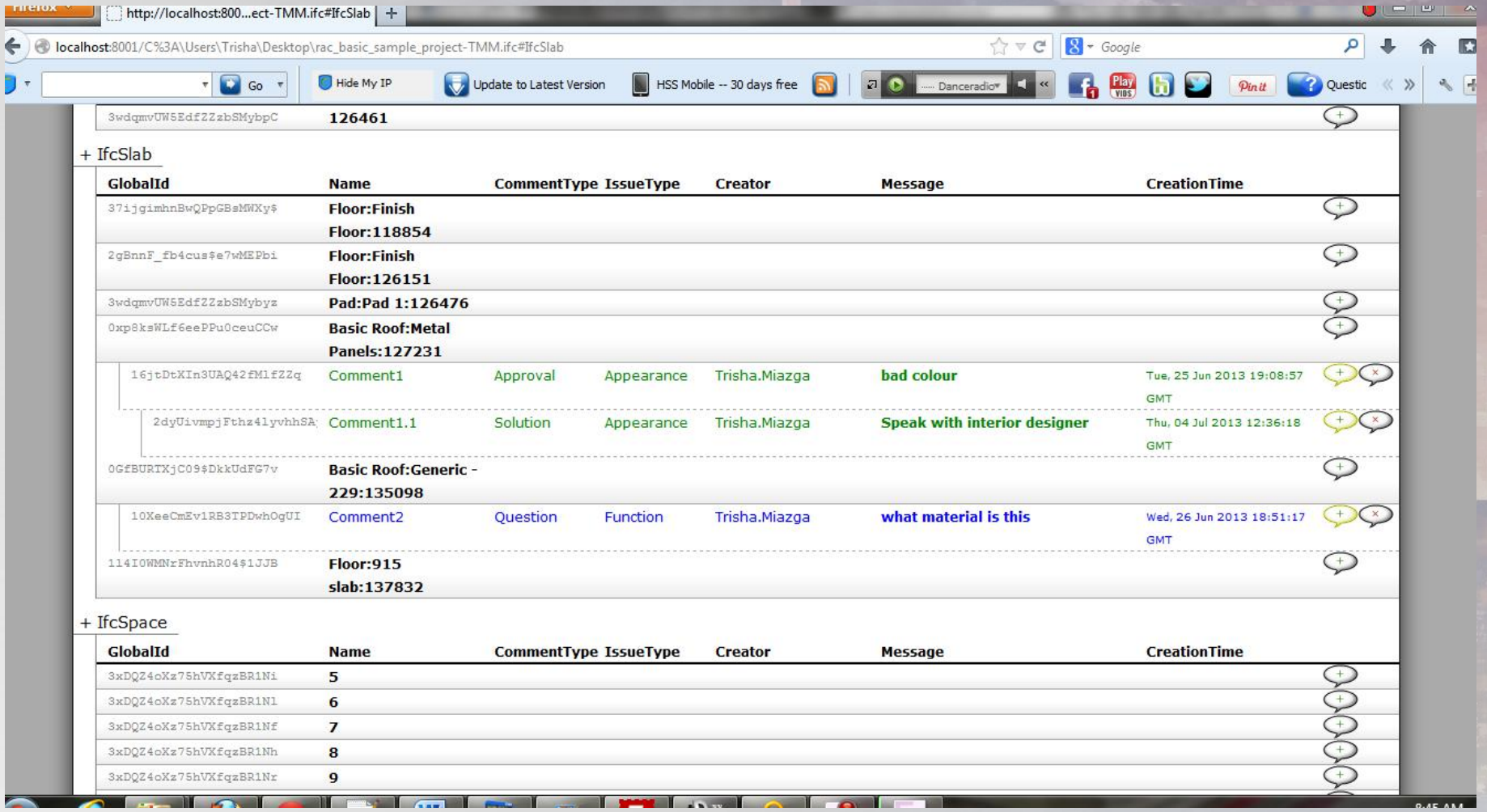


Comment Type	Directed To	Issue Type	Issue Sub-type	
[Menu]	[Text]	[Menu]	[Menu]	
Problem Question Solution Answer Recommendation Note		Code compliance	1 - General 3 - Fire Protection, Safety, Accessibility 4 - Structural 5 - Environmental Separation 6 - HVAC 7 - Plumbing 8 - Safety – Site, Demolition 9 - Housing, Small Buildings	[Text - Enter code reference]
		Appearance	Style Shape Finish Color Other	
		Constructability & Estimating	Supply Chain/Mat'l Availability Intersections/Interference Customization/Standardization Symmetry /Similarity Life Cycle Labor Installation Phasing Installation Ease & Clearance Other	
		Program requirements & Design intent	Social Performance Sustainability Other	
		Schedule	Design phase Construction phase Other	Increa Decrease

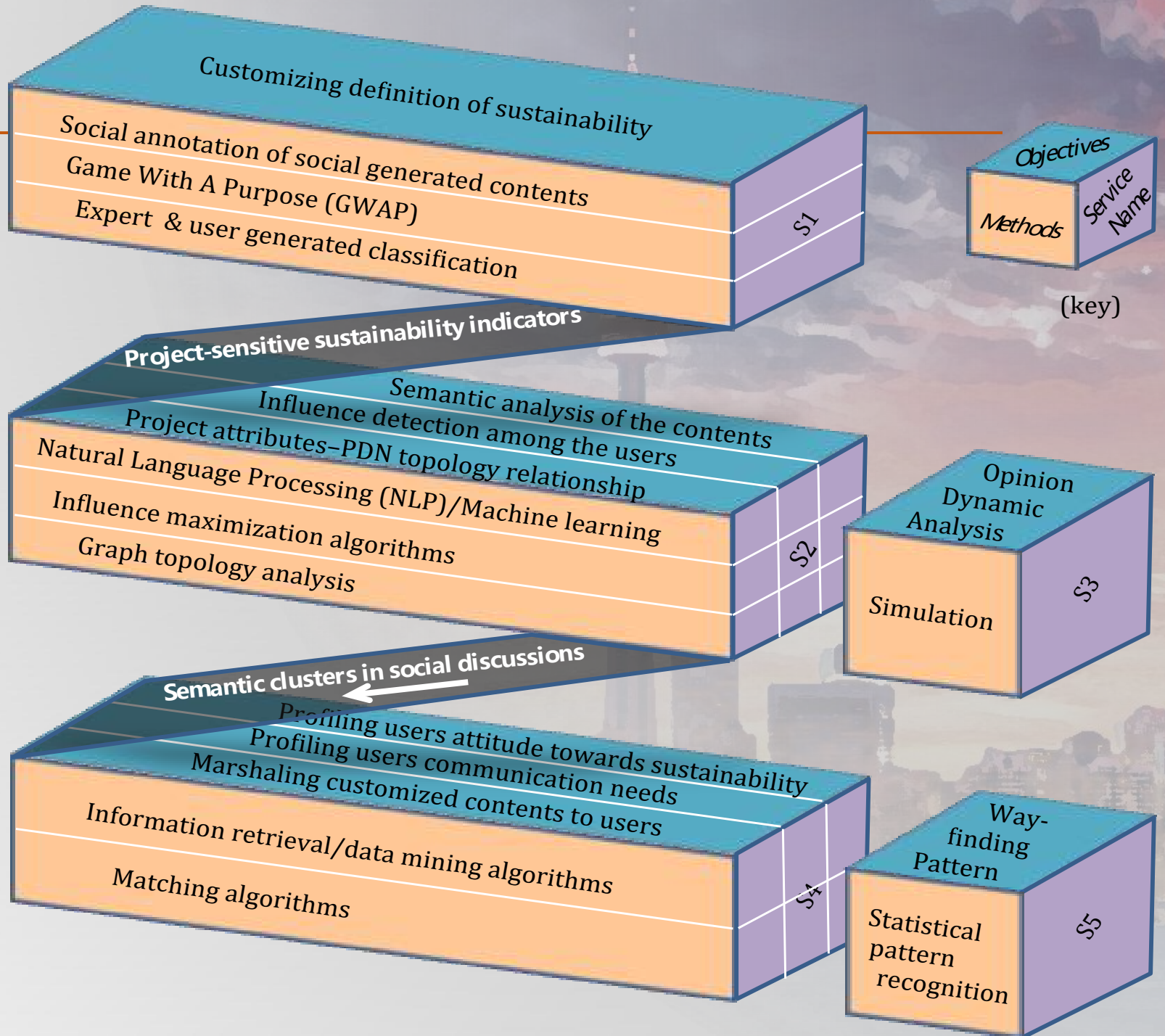
Comment repository



Tracking the debate: comment networks



Analyzing the results



The value proposition

Commenting is tied to IFC objects	Streamlined and intuitive reporting
	Profiling building components
Semantic analysis of comments	Understanding context and detecting issues
	Profiling topics
Network of people	Understand the dynamics of actor relations
	Profile actors
Product catalogue	Offering customization options
	Capturing selection patterns and rationales
Energy analysis	Promote green options
	Educate users
Trend analysis	Topic trends
	Cross-topic trends
Prediction	Better planning
	Re-use best practices/smart components

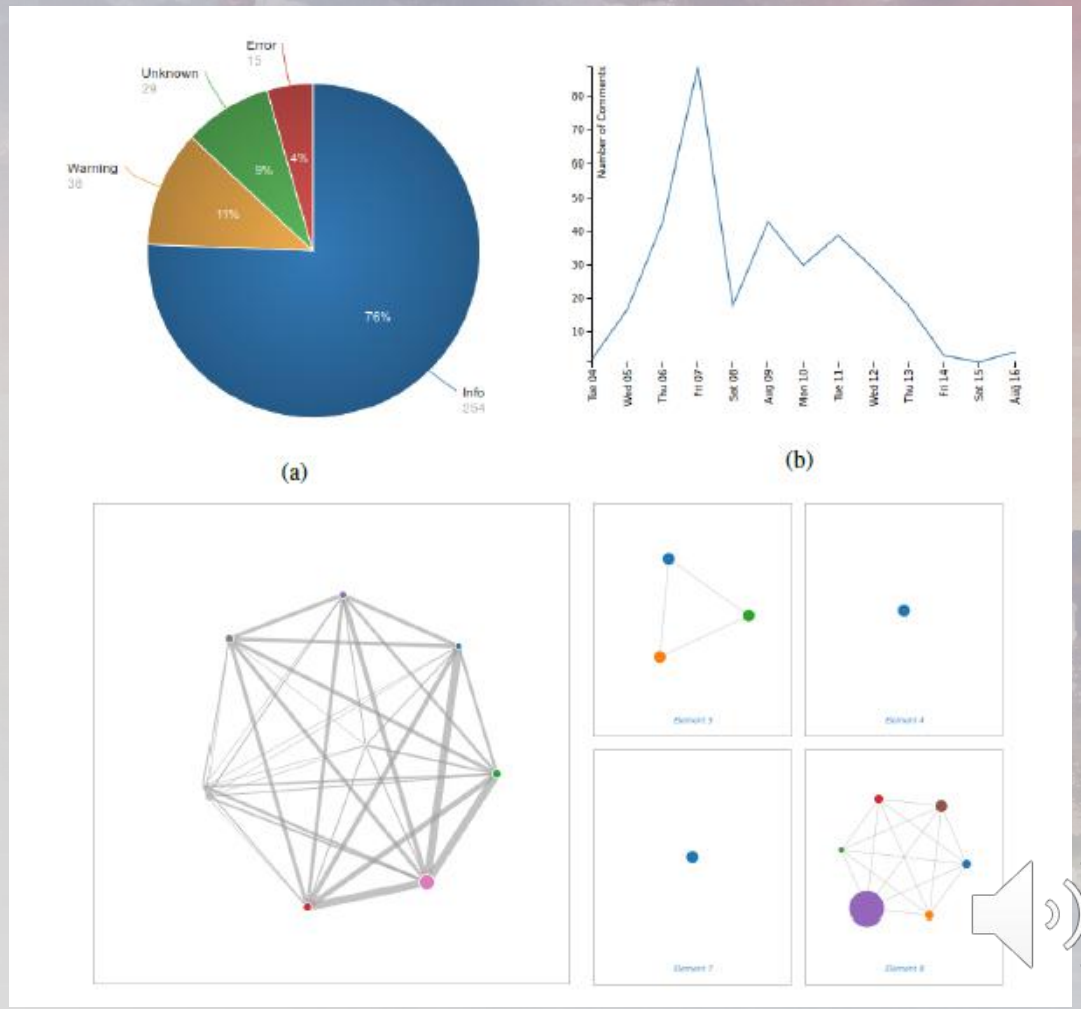

Future Plans

Smart elements (profiling element signatures)

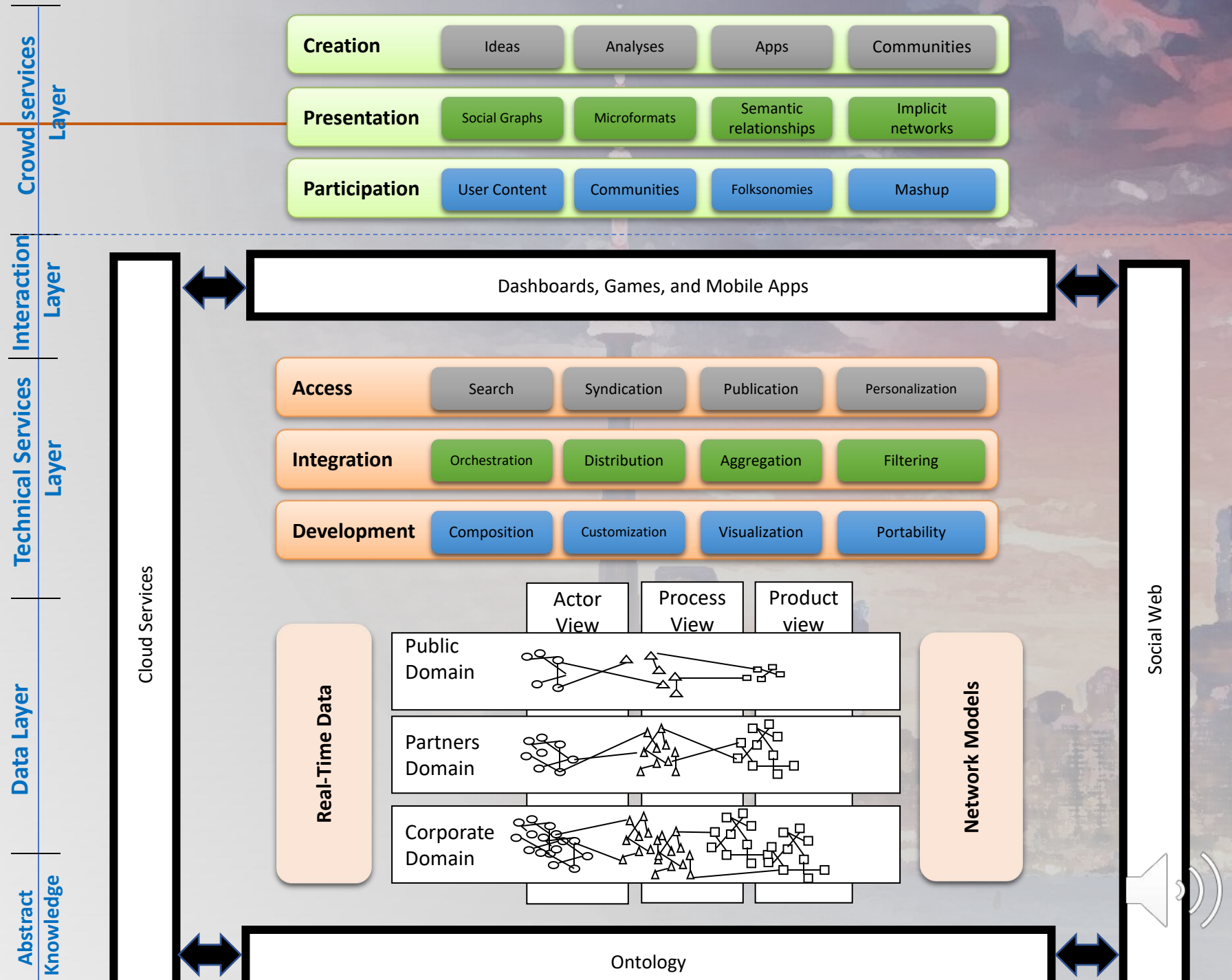
- Profile of users interested in the element
- Issues, ideas, problems with the element
- Issues, ideas problems for groups of elements

- Element-specific Analytics (Complete Graphs)
- Project-specific Analytics (Discussion Trends)
- Cross-project Analytics (Discussion Networks)

- What changes altered user or operator views
- Which user is predicted to provide what input
- What issues to expect with this element
- What alternative designs can be used
- Which other elements can match



Empowerment



Thanks