System modeling for energy-efficient and sustainable building design and city planning

Dr.-Ing. Philipp Geyer

MSE Colloquium München, 28.6.2012
Why do we need systems engineering for sustainability?

- Sustainability is multidisciplinary
- Involves physics, engineering, environmental science, economics …
- Disciplines interact and form a complex network of interdependencies
- Systems engineering and modelling helps to find well-performing configurations
Parametric Systems Modeling (PSM)
Synthesis of the System
Parametric Systems Modeling (PSM)
Analysis of the System
Watergy Building Berlin (de) / Greenhouse in Almeria (es)
Urban Systems Composition – Use Cases and Requirements

- **Use Case**: Heat and Cool
  - Requirement: Conditioned Space
    - Temp: 19°C ≤ T ≤ 26°C
    - Humidity: 35% ≤ RH ≤ 70%
    - Air Velocity: v_{Air} ≤ 0.5 m/s

- **Use Case**: Inhabit
  - Requirement: Food Production
    - 250 kg/yr per person
  - Requirement: Drinking Water Supply
    - 5 l/day per person
  - Requirement: Process Water Supply
    - 25 l/day per person, includes drinking water

- **Use Case**: Use Drinking Water
  - Requirement: Electric Energy
    - 2000 kWh/person/year

- **Use Case**: Clean Body
  - Requirement: Traffic Infrastructure
    - Private and public vehicles, emission-free

- **Use Case**: Clean Interior

- **Use Case**: Operate Light, Devices

- **Use Case**: Travel

**Subsystems**
- Building
- Desiccant System
- Productive Greenhouse
- Water Purification
- Urban Environment

**Requirements of the Building-City System**
- «derive»
- «satisfy»
Urban Systems Composition – Structure and Item Flows
Performance-oriented Design – Parametrics and MOEs

- **moe** Area Consumption
  - Total Area Consumption
    - $A_{\text{system}} = 29'000 \text{ m}^2$
    - $A_{\text{unsealed}} = 19'300 \text{ m}^2$
  - Unsealed Area Consumption
    - $A_{\text{total}}$
    - $A_{\text{add},1}$
    - $A_{\text{add},2}$

- **moe** Carbon Balance
  - $V_{\text{CO}_2, \text{total}} = -37 \text{ t/yr}$
  - $V_{\text{CO}_2, \text{GH}} = -87 \text{ t/yr}$
  - $V_{\text{CO}_2, \text{BdConstr}} = 50 \text{ t/yr}$

- Performance-oriented Design
  - **moe**
  - **moe**

- Total Area Consumption
  - $n_{\text{inhab}} = 330$
  - $A_{\text{traffic}} = 4'300 \text{ m}^2$
  - $A_{\text{BD}} = 12'800 \text{ m}^2$
  - $A_{\text{BD footprint}} = 5'400 \text{ m}^2$
  - $A_{\text{GH}} = 11'900 \text{ m}^2$

- Unsealed Area Consumption
  - $A_{\text{total}}$
  - $A_{\text{add},1}$
  - $A_{\text{add},2}$

- Traffic Area Dimensioning
  - $A_{\text{traffic}} = A_{\text{BD}} \cdot n_{\text{traffic ratio}}$
  - $n_{\text{traffic ratio}} = 0.3$

- Plot Area Dimensioning
  - $A_{\text{BD}} = A_{\text{floor space}} / n_{\text{plot ratio}}$
  - $n_{\text{plot ratio}} = 0.8$

- Buildings' Footprint
  - $A_{\text{BD footprint}} = A_{\text{floor space}} / (1 - p_{\text{constr+circ}}) / n_{\text{storey}} \cdot p_{\text{sealed area}}$
  - $A_{\text{floor space}} = 10'000 \text{ m}^2$
  - $n_{\text{storey}} = 4$
  - $p_{\text{sealed area}} = 150$
  - $p_{\text{constr+circulation}} = 30$

- CO₂ Balance Greenhouse
  - $t_{\text{life, BD}} = 50 \text{ yr}$
  - $K_{\text{CO}_2, \text{BD Constr}} = 250 \text{ kg/m}^2$
  - $K_{\text{CO}_2, \text{GH Constr}} = 40 \text{ kg/m}^2$
  - $t_{\text{life, GH}} = 15 \text{ yr}$
  - $K_{\text{CO}_2, \text{GH Growth}} = -10 \text{ kg/yr m}^2$
Nürnberg Weststadt – Sustainable development of a livable urban district
Conclusions

System Modeling Provides:

- Overview of Actual System Flows and Parametric Interdependencies
- An Interface between Geometric Modeling and Engineering and Simulation
- A Basis for Design Exploration and Computation (e.g. Design of Experiments or Optimization)