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Multimodel-based exploration of the building design space and its uncertainty

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DRESDEN
concept
Exzellenz aus
Wissenschaft
und Kultur

1. Multimodel method: motivation and usage
2. Extension of Multimodel method for BIM design space exploration
3. Integration of uncertainty in BIM information space
4. Simulation and collection of computed metrics

Intentions

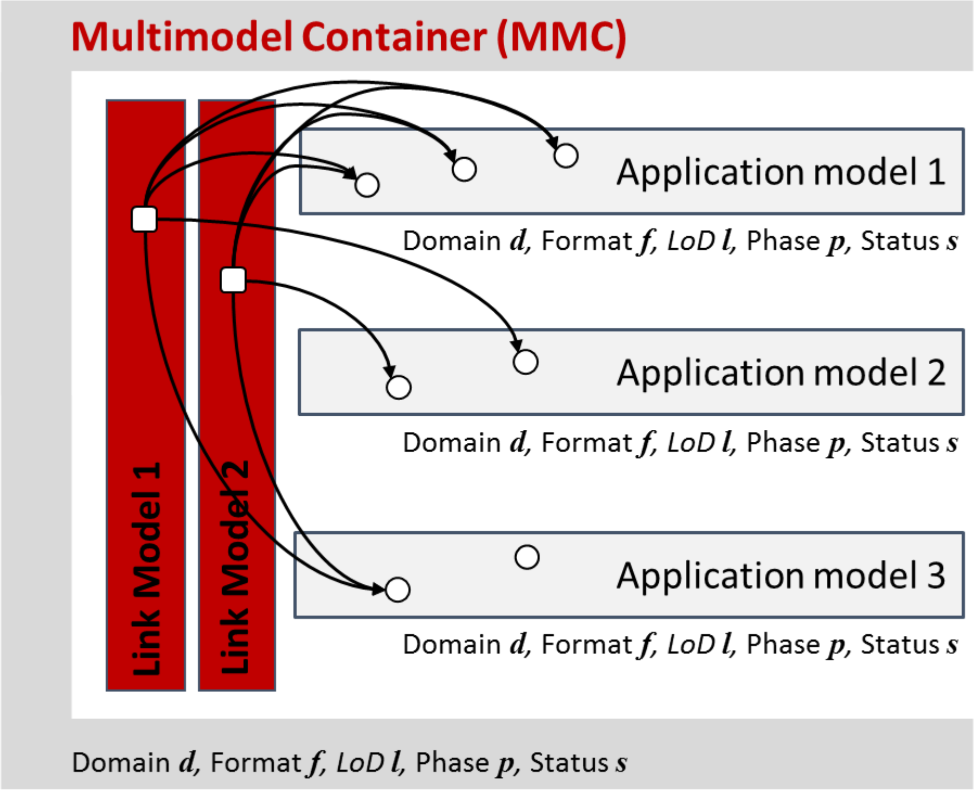
- Multimodel:
  - Initially developed in German research project „Mefisto“ (2009-2012), further development since then:
    - buildingSMART „MMC Project“
    - DIN-SPEC 91350
    - ISO/NP 21597 (Information Container for Data Drop)
  - Proposes a method and a data exchange model for integrating and linking together information from different engineering domains
  - Offers a exchangeable project data resource for enabling and easing collaboration in building design and construction.
  - Integrate heterogeneous and domain-specific data into a common data exchange model while maintaining native data formats.

- Goals of this work:
  - Enabling building design optimization with regard to several criteria reflecting different engineering domains.
  - Integrate different heterogeneous information from different application domains for the sake of a energy-efficient building design
  - Allow for making and modelling several changes in this information
  - Support uncertainty analysis of different building design options
  - In one single simulation request, simulates n (1 to hundreds) different building design options

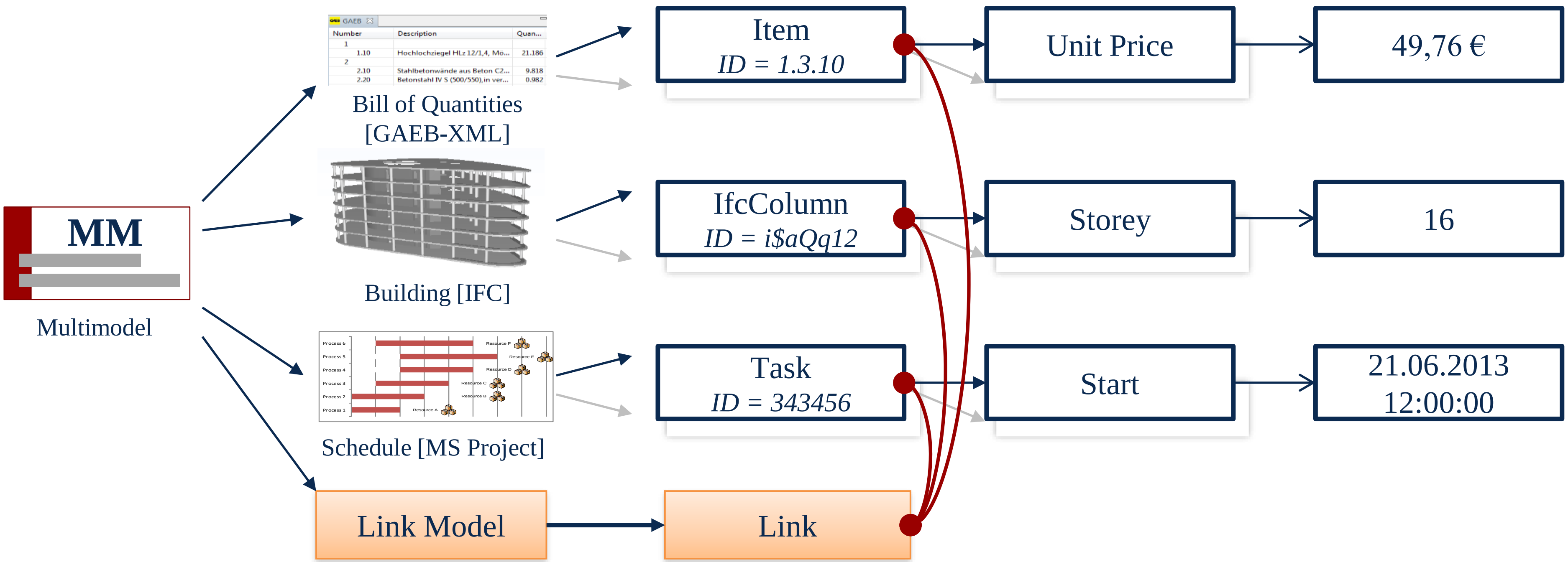
Background: multimodel method

Multimodel = set of m application models and n link models + annotations as metadata.

- Application Model
  - Embedded or referenced
  - Multiple files and formats (IFC, GaebXML, CSV, etc.)
- Link Model
  - links.xml
  - LinkModel.xsd
- Multimodel metadata
  - mulitimodel.xml
  - MultiModel.xsd
- Container
  - Contain all data mentionned above (e.g. as zip file)



Example of Multimodel for construction planning

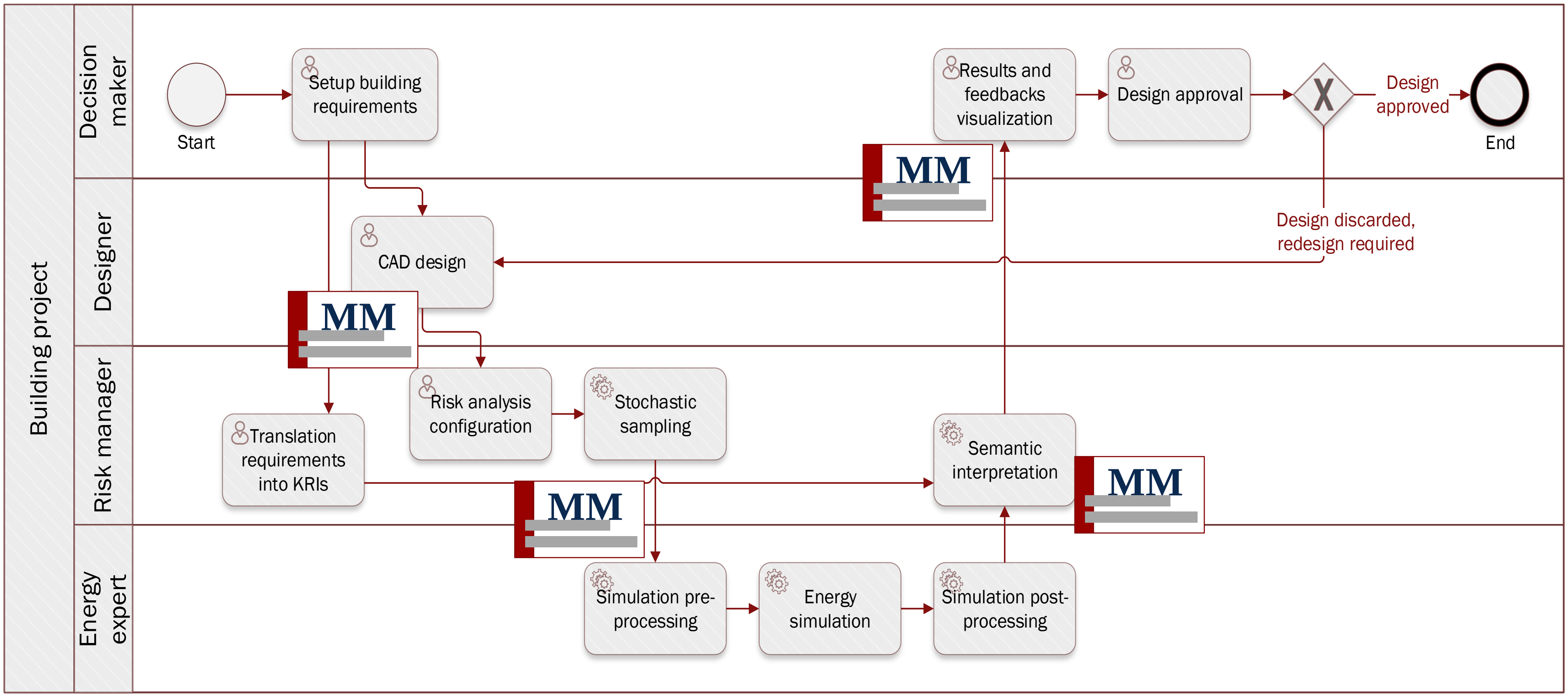


Multimodel:

Explicit, neutral & ID-based links between the application model's elements

Multimodel Container used as exchange model within a collaborative design work

- Simplified BPMN diagram of a design workflow focusing on building energy



Extension of MM for support of different design solutions and uncertainty analysis

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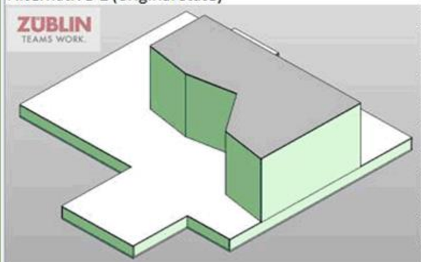
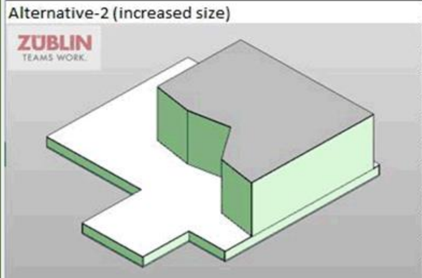
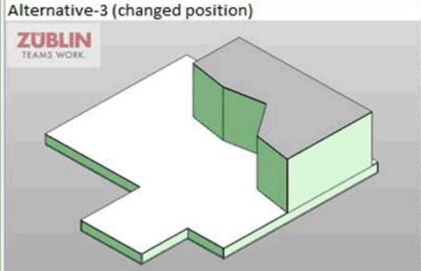
URBAN DESIGN VARIANTS

Alternatives (IFC model)	Architecture		Energy System	
	Variants		Variants	
Alternative-1 (original state)	**Variant Type-1**	**WWR**	**Variant Type-4**	**Heating system**
	Variant-1.1	35%	Variant-4.1	District heating
	Variant-1.2	50%	Variant-4.2	Natural Gas
			Variant-4.3	Solar heating
	Variant Type-2	**Orientation**		
	Variant-2.1	0°		
	Variant-2.2	180°		
	Variant Type-3	**Fassade/Shell**		
	Variant-3.1	Heavy		
	Variant-3.2	Lightweight		
Alternative-2 (increased size)	**Variant Type-1**	**WWR**	**Variant Type-4**	**Heating system**
	Variant-1.1	35%	Variant-4.1	District heating
	Variant-1.2	50%	Variant-4.2	Natural Gas
			Variant-4.3	Solar heating
	Variant Type-2	**Orientation**		
	Variant-2.1	0°		
	Variant-2.2	180°		
	Variant Type-3	**Fassade/Shell**		
	Variant-3.1	Heavy		
	Variant-3.2	Lightweight		
Alternative-3 (changed position)	**Variant Type-1**	**WWR**	**Variant Type-4**	**Heating system**
	Variant-1.1	35%	Variant-4.1	District heating
	Variant-1.2	50%	Variant-4.2	Natural Gas
			Variant-4.3	Solar heating
	Variant Type-2	**Orientation**		
	Variant-2.1	0°		
	Variant-2.2	180°		
	Variant Type-3	**Fassade/Shell**		
	Variant-3.1	Heavy		
	Variant-3.2	Lightweight		

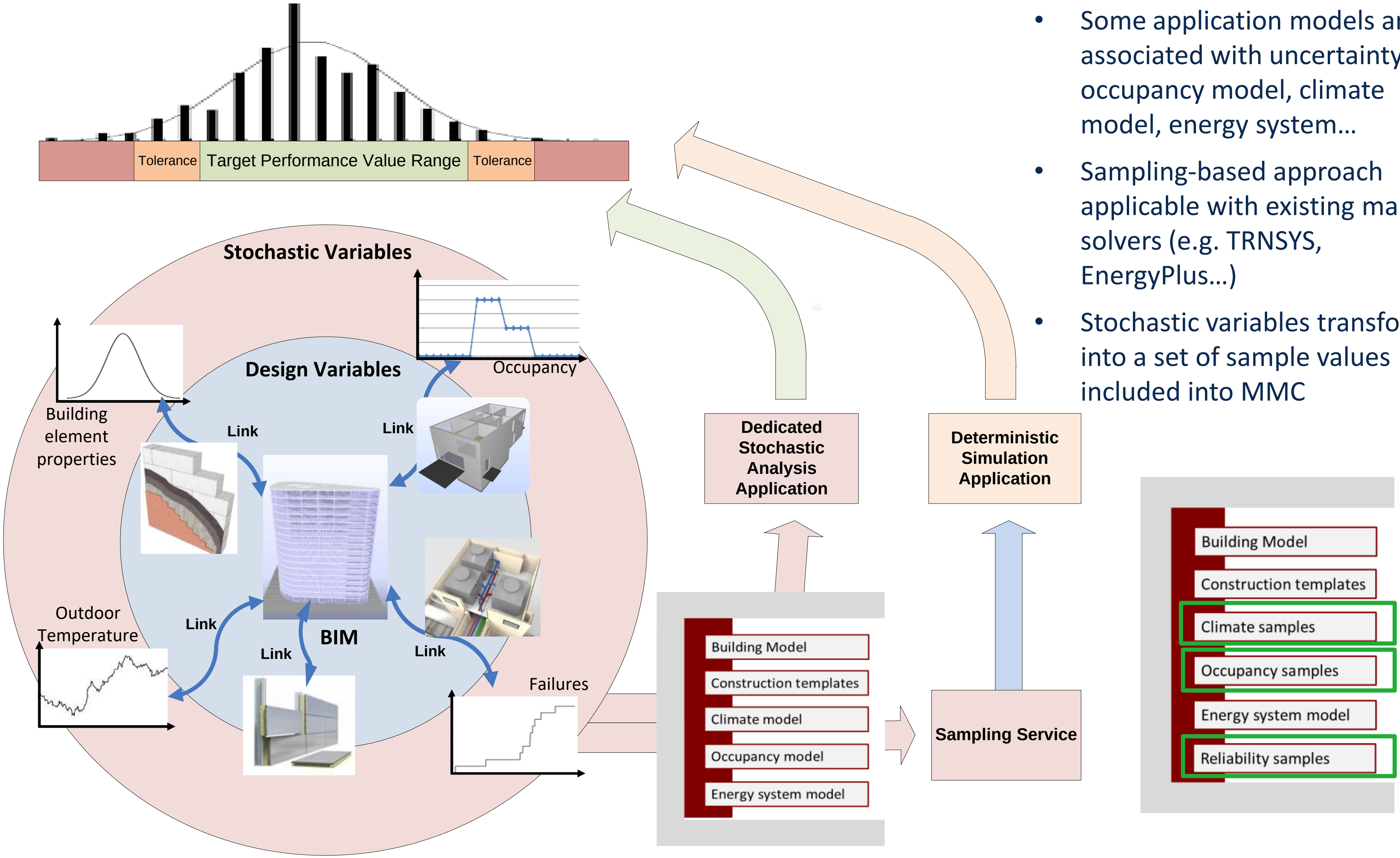
IFC model as central product model

Data from other application models: **product templates**, **district energy system model**, etc.

3 levels of Multimodel data variations:

- Design alternatives:
  - one IFC model each
- Design variants:
  - Based on design alternatives
  - one Link Model each
- Stochastic realizations:
  - Based on design variants
  - Set of randomly sampled values of some specific variables

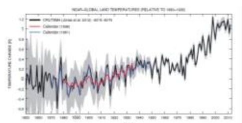
Integration of uncertainty in analysis workflow



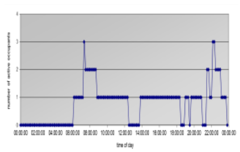
- Some application models are associated with uncertainty: e.g. occupancy model, climate model, energy system…
- Sampling-based approach applicable with existing market solvers (e.g. TRNSYS, EnergyPlus…)
- Stochastic variables transformed into a set of sample values included into MMC

Risk metrics derived from uncertainty and its simulation

Stochastic variables (Regressors)



Climate



Building usage

Component failures

Cost KRIs
- Operation costs variance
- Maintenance costs variance
- Investment costs variance
- …

Sustainability KRIs
- Energy demand variance
- CO2 emission variance
- …

Vulnerability KRIs
- System failure rate
- Average unvailability
- Mean Time to Failure
- …

Occupancy modelling for energy simulation:

- Occupants interact with the energy system in two ways, indirectly by emitting heat, and directly by interacting with the energy system or energy relevant appliances (e.g. light switches)
- Foundation for both is the presence of the occupant

Method: 1st order Markov Chain (Richardson et al., 2008)

- Simulates number of present/active occupants per zone
- Differentiates between zone types (e.g. kitchen, bureau, …) and day types (e.g. weekday, weekend)
- Flexible modelling and fast computation time

Sampling service:

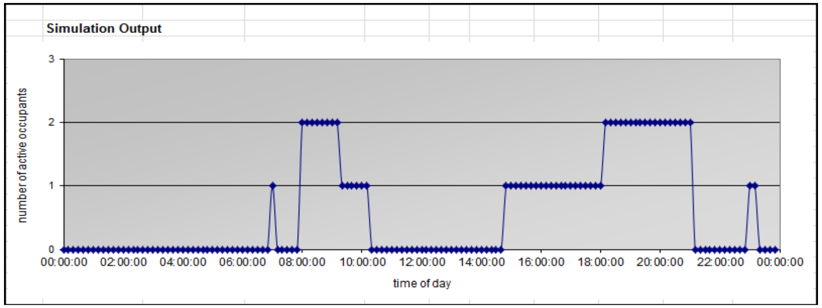
Occupancy data (room types and max nb of occupants) preliminary linked with IFC model in MMC

↳ Use of "transition probability matrices"

↳ Generation of samples (time series of occupant numbers)

Data generated by sampling for occupancy:

- From each transition matrix, an arbitrary number of samples can be generated
  - ➢ Time series representation:



Graphical representation of 1 sample of occupant numbers

  - ➢ Tabular representation for further usage in energy simulation tools:

	Time.stamp	Occupancy.density.1	Occupancy.density.2	Occupancy.density.3	Occupancy.density.4
97	16.000	0.15	0.10	0.10	0.00
98	16.167	0.15	0.15	0.15	0.00
99	16.333	0.15	0.15	0.15	0.00
100	16.500	0.10	0.15	0.15	0.00
101	16.667	0.10	0.15	0.15	0.00
102	16.833	0.10	0.15	0.15	0.00
103	17.000	0.10	0.15	0.15	0.00
104	17.167	0.10	0.15	0.20	0.00
105	17.333	0.15	0.15	0.20	0.00
106	17.500	0.15	0.15	0.20	0.10
107	17.667	0.15	0.20	0.25	0.10
108	17.833	0.15	0.20	0.25	0.10
109	18.000	0.15	0.15	0.25	0.15
110	18.167	0.15	0.15	0.25	0.15
111	18.333	0.15	0.10	0.25	0.10
112	18.500	0.20	0.10	0.25	0.00
113	18.667	0.20	0.10	0.25	0.00
114	18.833	0.20	0.10	0.25	0.00
115	19.000	0.15	0.10	0.25	0.00

Example of 4 samples with 10 minute time step and occupancy density (occupant/m²)

Climate data

- For enhanced accuracy, the climate data samples are real weather data records from the past that are formatted in the weather data format TRY.

Reihenfolge der Parameter:

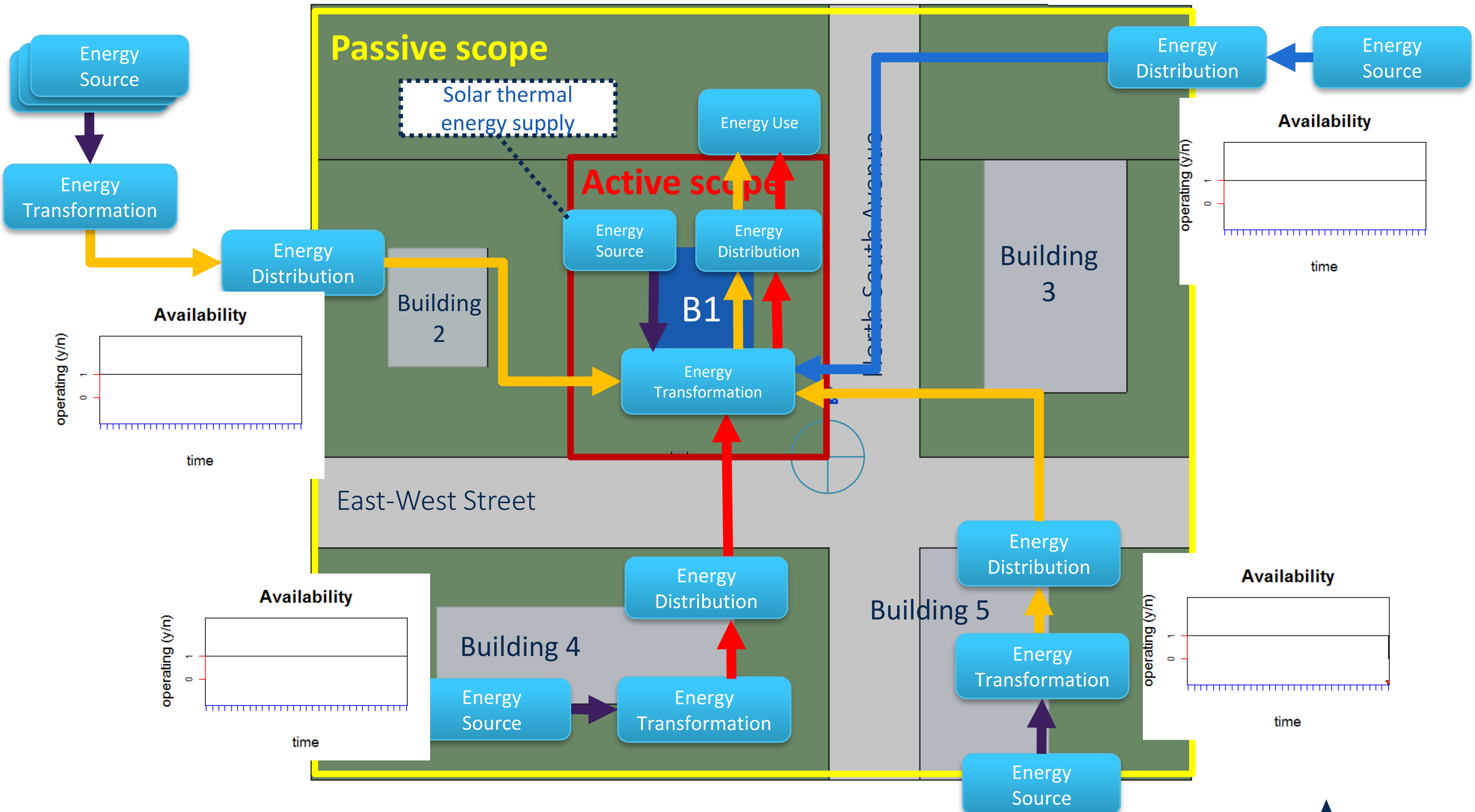
RG	TRY-Region		{1..15}
IS	Standortinformation		{1,2}
MM	Monat		{1..12}
DD	Tag		{1..28,30,31}
HH	Stunde (MEZ)		{1..24}
N	Bedeckungsgrad	[Achtel]	{0..8;9}
WR	Windrichtung in 10 m Höhe über Grund	[°]	{0;10..360;999}
WG	Windgeschwindigkeit in 10 m Höhe über Grund	[m/s]	
t	Lufttemperatur in 2m Höhe über Grund	[°C]	
p	Luftdruck in Stationshöhe	[hPa]	
x	Wasserdampfgehalt, Mischungsverhältnis	[g/kg]	
RF	Relative Feuchte in 2 m Höhe über Grund	[%]	{1..100}
W	Wetterereignis der aktuellen Stunde		{0..99}
B	Direkte Sonnenbestrahlungsstärke (horiz. Ebene)	[W/m²]	abwärts gerichtet: positiv
D	Difuse Sonnenbetrahlungsstärke (horiz. Ebene)	[W/m²]	abwärts gerichtet: positiv
IK	Information, ob B und oder D Messwert/Rechenwert		{1;2;3;4;9}
A	Bestrahlungsstärke d. atm. Wärmestrahlung (horiz. Ebene)	[W/m²]	abwärts gerichtet: positiv
E	Bestrahlungsstärke d. terr. Wärmestrahlung	[W/m²]	aufwärts gerichtet: negativ
IL	Qualitätsbit für die langwelligen Strahlungsgrößen		{1;2;3;4;5;6;7;8;9}

RG	IS	MM	DD	HH	N	WR	WG	t	p	x	RF	W	B	D	IK	A	E	IL
***																		
9	1	1	1	1	3	200	3.1	-3.6	969.1	2.3	77	-1	0	0	9	206	-285	9
9	1	1	1	2	1	160	2.4	-4.8	966.6	2.2	80	-1	0	0	9	206	-285	9
9	1	1	1	3	0	160	2.4	-5.8	964.5	2.0	78	-1	0	0	9	204	-283	9
9	1	1	1	4	1	190	2.2	-5.7	963.8	2.0	78	-1	0	0	9	207	-286	9
9	1	1	1	5	2	130	2.5	-5.7	963.0	1.8	70	-1	0	0	9	202	-280	9
9	1	1	1	6	4	170	2.0	-5.0	962.2	1.7	62	-1	0	0	9	216	-288	9
9	1	1	1	7	5	160	3.0	-5.2	961.5	1.6	60	-1	0	0	9	221	-287	9
9	1	1	1	8	6	170	3.0	-3.5	961.0	1.8	59	-1	0	0	9	223	-294	9
9	1	1	1	9	7	180	5.0	-2.7	960.5	1.9	59	-1	6	36	9	249	-300	9
9	1	1	1	10	7	190	5.0	-0.9	959.9	1.7	46	-1	11	75	9	239	-306	9
9	1	1	1	11	6	160	7.0	-0.3	959.2	1.8	46	-1	97	78	9	238	-309	9
9	1	1	1	12	6	170	6.0	1.2	958.1	1.6	37	-1	106	97	9	249	-316	9

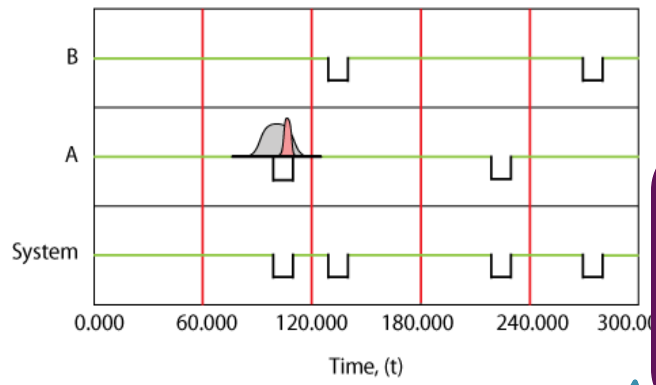
Variables:
- Outdoor temperature
- Wind speed
- Wind direction
- Humidity
- Solar radiation
- Etc…

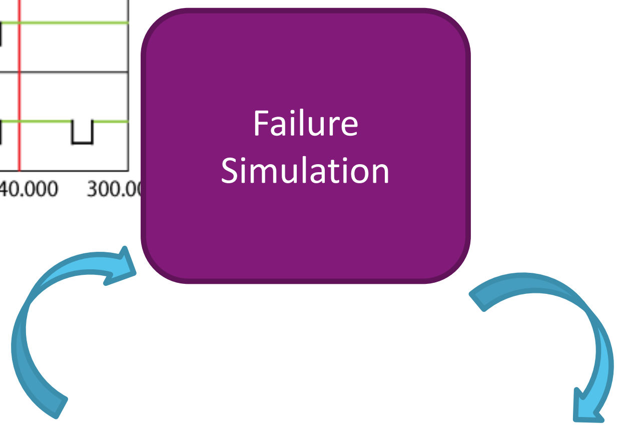
Example of weather data time series in the TRY format. Data for Chemnitz, Germany, retrieved from DWD (Deutscher Wetterdienst)

Application to reliability analysis of energy system



Application to reliability analysis of energy system





Top/Down curves expressed as a set time series embedded in the Multimodel Container and linked to related ES components:

	Energy system component failures				
time	Component A	Component B	Component C	...	component N
instant 0	1	1	1	...	1
instant 1	1	0	1	...	1
instant 2	1	1	1	...	1
...	0	1	1	...	1
...	1	1	1	...	1
...	1	1	0	...	1
...	1	1	1	...	0
...	1	1	1	...	1
...	1	0	1	...	1
...	1	1	1	...	1
...	0	1	1	...	0
instant n	1	0	1	...	1

time	**Energy system failures**
instant 0	1
instant 1	1
instant 2	1
...	0
...	1
...	1
...	0
...	1
...	1
...	1
...	0
instant n	1

Data variation model example for energy simulation in early design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```


Related IFC-GUID (one IfcBuilding and 20 IfcRoom entities)

3 design variants

1st sample

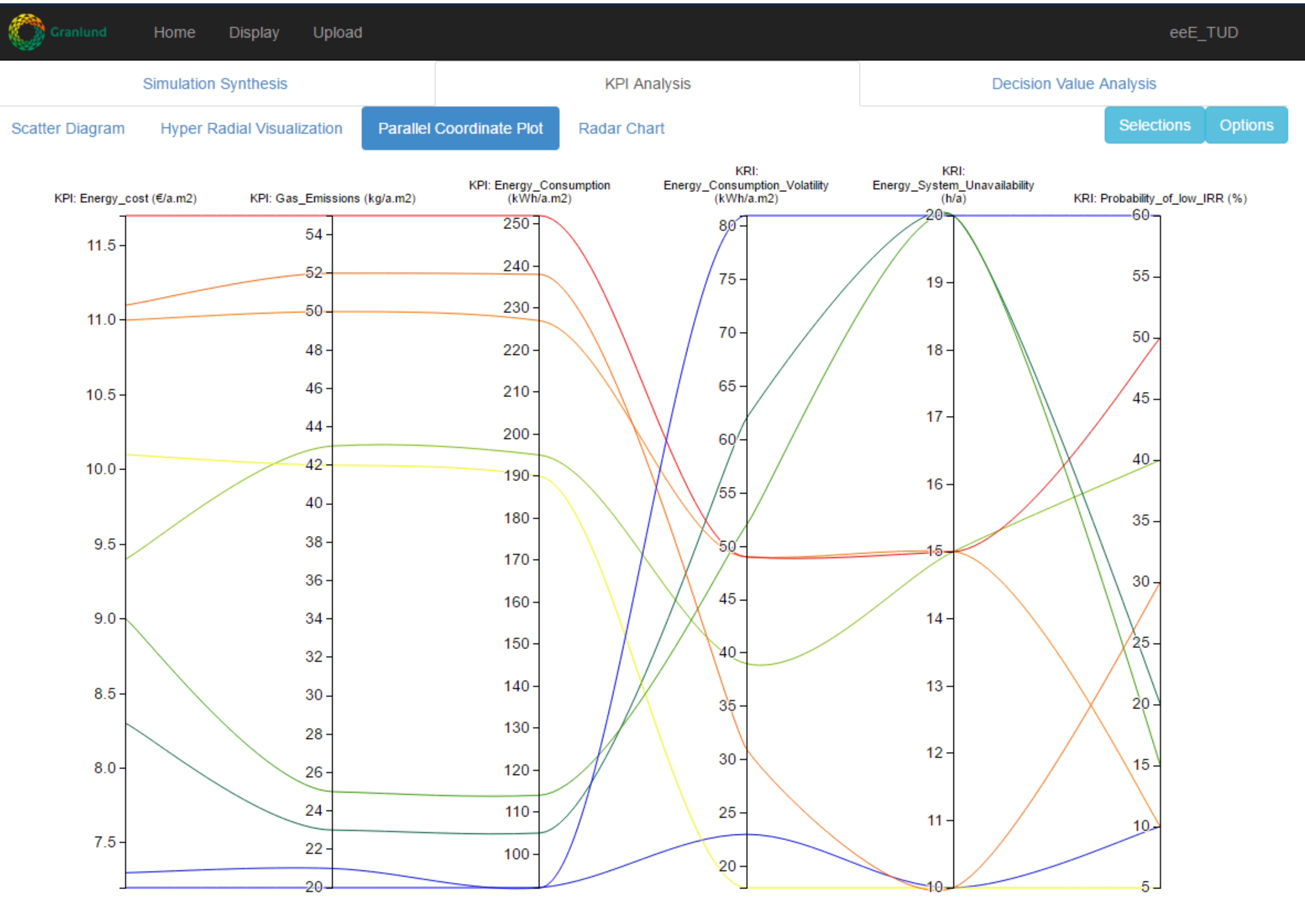
1 Cimate + 20 occupancy time series

n samples

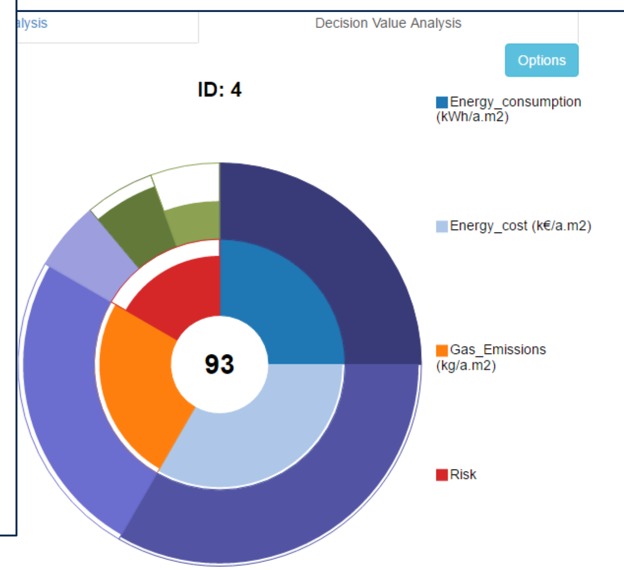
Visualization of results from uncertainty analysis

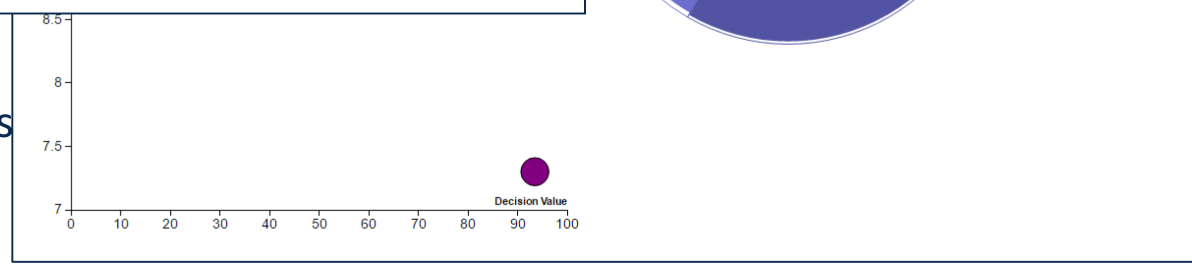
- Visualization of simulation results in term of energy demand for heating by three different design variants (Granlund Optimizer)

Risk-aware decision Making



Vizualisation in KPA Tool from Granlund





Weighting and normalization of KRIs for assessing compliance of actual risk level against risk appetite

Conclusion and future Activities

- Conclusion:
  - multimodel method extended to fasten and facilitate setting and simulation of a large amount of variants and uncertainties in a collaborative building design workflow.
  - Method adapted for assessing uncertainty on the basis of standard simulation tools
  - Generic variation model was developed for describing stochastic realizations of BIM data as well as several types of design alternatives

- Future works:
  - Encompass more simulation domains e.g. structural analysis, reliability analysis, life cycle cost…
  - Apply for sensitivity analysis
  - Couple with cloud-computing technologies

Thank you for your attention