# Hochschule für Technik Stuttgart

HFT Research

## 3D-SDI contribution to energy-efficient cities

Prof. Dr. Volker Coors, HFT Stuttgart
3rd Int. Workshop of „Geotym" project, 24.9.2012



## Motivations and Challenges of 3D City Modeling

***A rapid transition of urban areas towards energy efficiency and the adaption to challenges posed by climate change are highly required…***

- 3D city modeling can play an essential role for energy planners and municipal managers, supporting them with:
  - energy diagnosis of the present situation
  - Coordination of strategies to decrease building energy demand
  - …and increase sustainable energy supply concepts
  - development of strategies for sustainable transport
- A common, flexible and open city modeling standard is need to:
  - deal with different levels of details and data availabilities/qualities
  - store and exchange numerous and miscellaneous urban data on a unique support
  - provide a visualization of results

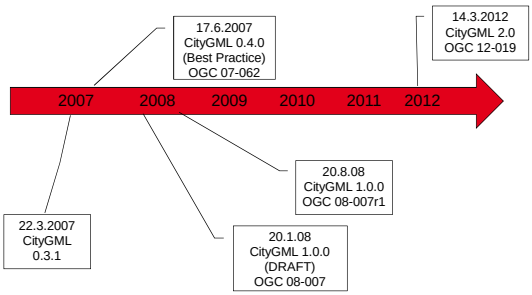


## From 2D to 3D

**Quelle: Freie und Hansestadt Hamburg, Landesbetrieb Geoinformation und Vermessung**



## Standard: CityGML





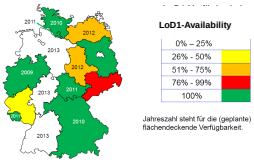

## 3D Citymodels based on CityGML

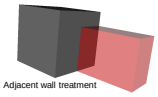
CityGML

- Standardized (OGC) open data model for virtual 3D Citymodels
- Based on ISO 19139 Standard GML (XML based), extended for urban structures
- Spatio-semantic Model, linking geometry, topological relationships, semantic data and design property (for visualization)

Strengths

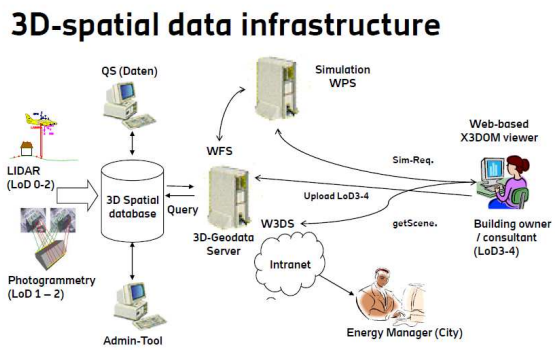
- open standard, regularly updated
- already wide-used (at least in Germany)
- XML based and extendable
- many possibilities of spatial analysis
- modeling with 4 possible Level of Details (LOD)



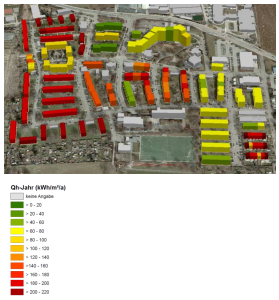



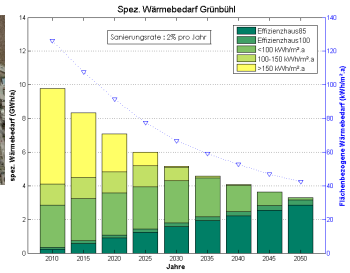



## 3D geospatial data infrastructure



## Simulation of district heating energy demand

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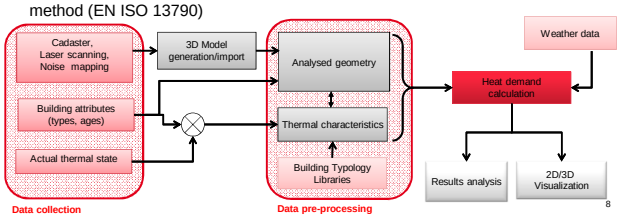
## District heat demand calculation

**Development of an integrated process of district heat demand calculation**

1. Generation/Import and quality control of a **3D Citymodel** (CityGML LoD1/LoD2)
2. Automatized calculation of **building envelop thermal characteristics**
   - use of national **building libraries** (building types/ages)
   - **updated** with additional information (precise Uvalues, refurbishment etc.)
3. Geometrical Analysis of 3D Model, pre-processing with building parameters
4. Heat demand calculation for each building through the **monthly energy balance** method (EN ISO 13790)

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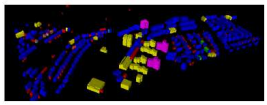
## Analysis of 3D City model

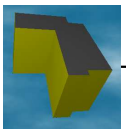
- Building classification

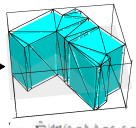


- Volume Calculation
  - ➢ tetraeder decomposition
- Extraction adjacent walls

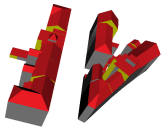
Segmentation and Window detection

- Window extraction from textures





$$V = \sum_{i=1}^{n} \frac{|\det(a_i - b_i, b_i - c_i, c_i - d_i)|}{6}$$



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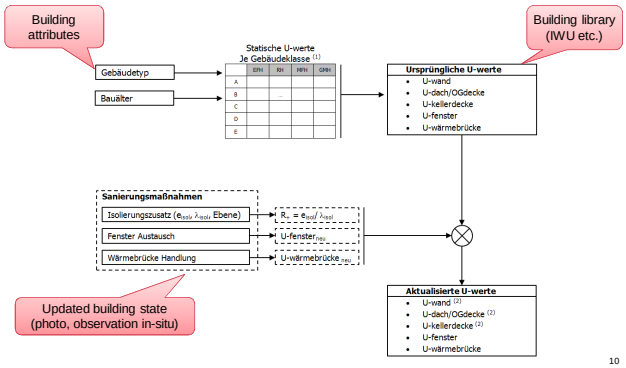
## Thermal Data processing

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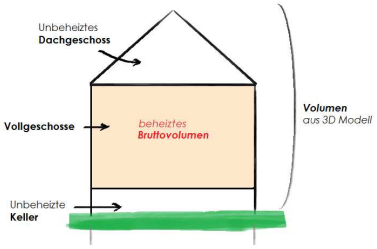
## Geometrical data processing




The **heated volume, wall, cellar wall and window areas** must be corrected between the 3D Model and the thermal building model, particularly if**:**

- **Cellar type** = heated/non-heated
- **Attic storey type** = non-heated
- **Usage ALKIS** = commercial-residential building

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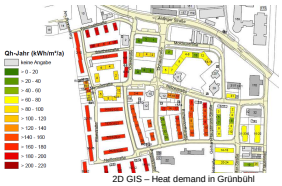
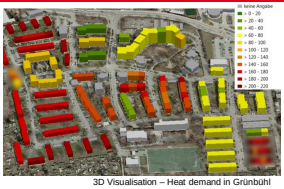
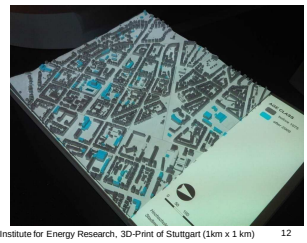
## Results Visualization




2D GIS – Heat demand in Grünbühl



3D Visualisation – Heat demand in Grünbühl





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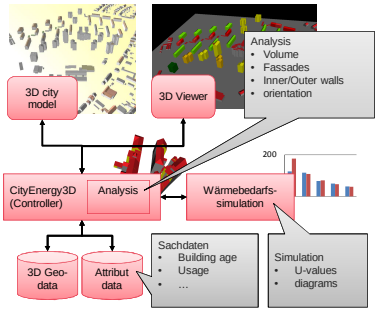
## Software development at HFT

# CityEnergy3D




- nput: 3D spatial database of CityGML file
- Simulation of energy demand and scenarios
- PV analysis and shadow calculation
- Standardization: OGC services and CityGML ADE
- Extension to other aspects of urban planning



## District Heat Demand Calculation – Case studies

Two case studies of District Heat Demand Calculation, with different level of details and input data qualities

- District Grünbühl, in Ludwigsburg
- District Rintheim, in Karlsruhe



## Case study 1 : Ludwigsburg – Grünbühl

**Case Study 1: Post-war district**

**Ludwigsburg – Grünbühl**

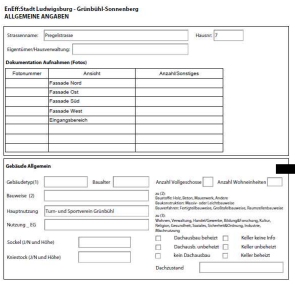
- Living area: 77.000 m²
- Energy supply: mainly Gas boilers
- 3D model : LoD1 (roof area from laser scanning)
- Uvalues deduced from building age and types Information, updated with outside observations



## Case study 1 : Ludwigsburg – Grünbühl

**Data collection**

- For apartment dwellings → building data collected from owner companies
- For private buildings → on-site observation (survey)




| GEB_ID | |
|---|---|
| STRASSE_NAME | |
| STRASSE_NR | |
| NUTZ_ALK | nach ALK Definition (Whs; Wghs; Schule …) |
| WOHNTYP | nach IWU Definition (EFH; RH; MFH; GMH…) |
| GEBALTKLASSE | nach IWU Definition (A; B;…; J ) |
| VOLLGESCHOSSE | Integer |
| DACHGESCHOSS_TYP | Kein / Unbeheizter/ Beheizter Dachgeschoss |
| KELLER_TYP | Keine / Unbeheizte / Beheizte Keller |
| SANIERUNGSJAHR | |

| FASSADE_ID | |
|---|---|
| WRICHTUNG | Azimuth |
| WDAEMD | Dicke der Isolierstoff |
| WDAEMLAMBDA | Wärmeleitfähigkeit der Isolierstoff |
| WUWERT | Wand U-Werte wenn bekannt |
| FANTEIL | Fenster Anteil (%) |
| FTYP | (1 – 5) |
| FUWERT | Fenster U-Wert wenn bekannt |
| FSCHATTEN | Fenster Schatten Faktor |
| WSCHAD | Wand Schädigung (1 - 5) |



## Case study 1 : Ludwigsburg – Grünbühl

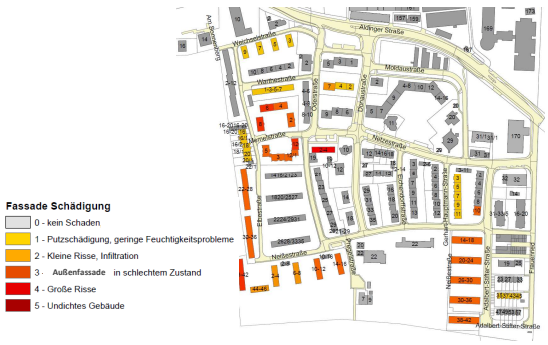
**Outside facade state of post-war buildings**




## Case study 1 : Ludwigsburg – Grünbühl

**Integration of a „facade damage index“ (0 - 5) in the 3D Model dataset**

- Used for the infiltration rate assessment
- Potential use to define refurbishment priorities in a refurbishment scenario



## Case study 1 : Ludwigsburg – Grünbühl

**Building and refurbishment year**

- 1/3 post-war buildings
- Since 1990, 1% of the district living area is refurbished yearly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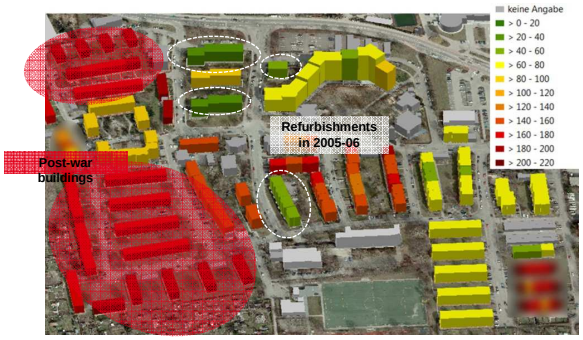
## Case study 1 : Ludwigsburg – Grünbühl

**Heat demand calculation**

- Average: 106 kWh/m²/yr
  - ➢ from 30 for newly refurbished buildings to 216 kWh/m²/yr for old leaky buildings

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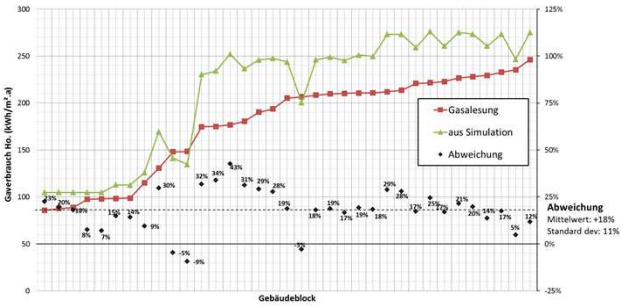
## Case study 1 : Ludwigsburg – Grünbühl

**Comparison with gas consumptions* (average over the last 6 years)**

➢ Global Deviation: 18%




* Assumptions : Domestic hot water: 20 kWh/m²; Gas boiler efficiency: 85%

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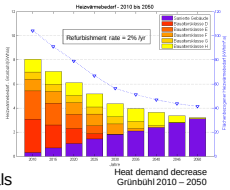
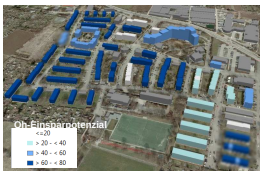
## Use of 3D City Model for urban planning




Heat demand decrease Grünbühl 2010 – 2050

Use of 3D City Model for urban planning

- Refurbishment scenario and energy saving potentials
- Definition of refurbishment priorities, temporal planning of the urban renewal
- Calculation of refurbishment investment/global energy costs




Energy savings [%] - Grünbühl

Refurbishment Costs [€/m²] - Grünbühl

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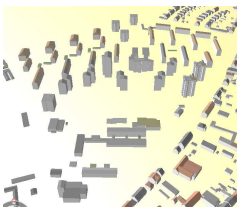
## Case study 2 : Karlsruhe – Rintheim

**Case Study 2: partly refurbished Apartment dwellings**

**Karlsruhe – Rintheim**

- Living area: 65.000 m² (36 Buildings – 1/3 refurbished)
- Energy supply: Gas boilers
- 3D model: Karlsruhe LoD2 model (roof area from laser scanning)
- Precise information on u-values (building classification in 6 types)



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## Case study 2 : Karlsruhe – Rintheim

**Classification of the building stock in 6 Building Types with same thermal characteristics**

- Type 1 and 2: original state, not refurbished
- Type 3: partly refurbished (facade in 1975, roof in 2003)
- Type 4 to 6.2: full-refurbishment of buildings between 1998 and 2008

| Building Class | Type 1 | Type 2 | Type 3 | Type 4 | Type 5 | Type 6.1 | Type 6.2 |
|---|---|---|---|---|---|---|---|
| Building Type | Multi family | High rise | Large multi family | Multi family | Multi family | High rise | Multi family |
| Year of construction / Full refurbishment | 1954-1956 | 1974 | 1975 | 1998 | 2000 | 2007 | 2008 |
| U-value wall | 1,40 | 0,80 | 0,40 | 0,30 | 0,20 | 0,10 | 0,10 |
| U-value roof / top level | 1,17 | 0,35 | 0,20 | 0,35 | 0,35 | 0,10 | 0,20 |
| U-value basement ceiling | 1,65 | 0,71 | 0,85 | 0,47 | 0,47 | 0,25 | 0,38 |
| U-value window | 3,20 | 2,70 | 2,70 | 1,70 | 1,40 | 1,30 | 1,30 |
| g-value window | 0,80 | 0,76 | 0,76 | 0,63 | 0,62 | 0,60 | 0,60 |
| ΔU thermal bridge | 0,10 | 0,10 | 0,10 | 0,05 | 0,05 | 0,03 | 0,03 |
| air exchange rate | 0,70 | 0,70 | 0,70 | 0,60 | 0,60 | 0,60 | 0,60 |

Uvalues from Büro IGK-Kaiserslautern

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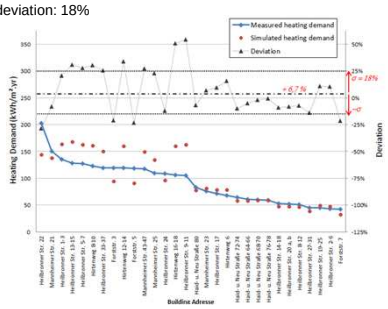
## Case study 2 : Karlsruhe – Rintheim

**Individual building comparison – Simulated and measured heat demand***

- Average gas consumption over 3 years
- Total district deviation: **6,7%**
- Standard deviation: 18%



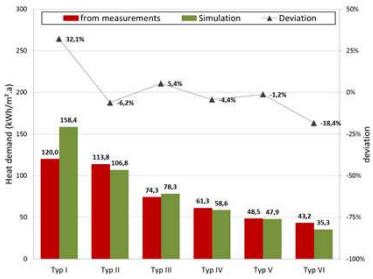

* Assumptions: domestic hot water: 20 kWh/m²yr; Gas boiler efficiency: 88%



## Case study 2 : Karlsruhe – Rintheim

**Building type comparison – Simulated and measured heat demand***

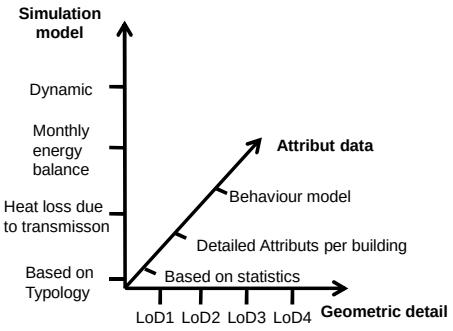
- Building types II - V match well (deviation ~5%)
- Low-energy building type VI → - 18% under-estimated heat demand
- Non-refurbished building type I → 32% over-estimated heat demand




* Assumptions: domestic hot water: 20 kWh/m²yr; Gas boiler efficiency: 88%



## Impact factors

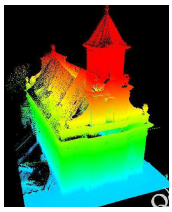





## Open issues

What do we gain with LoD 3 models?

LoD2 + fassade geometry



Ludwigsburg, mobiler Laserscan

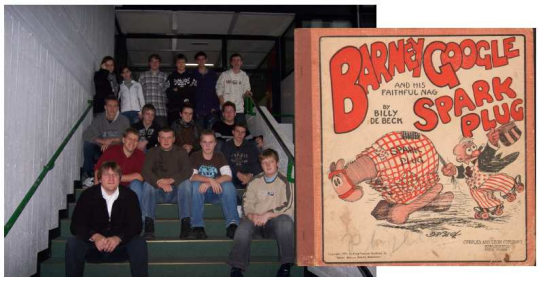
Pilot Schamhauser Park, Ostfildern, LoD 3



## Open issues

How do we get better attribute data?

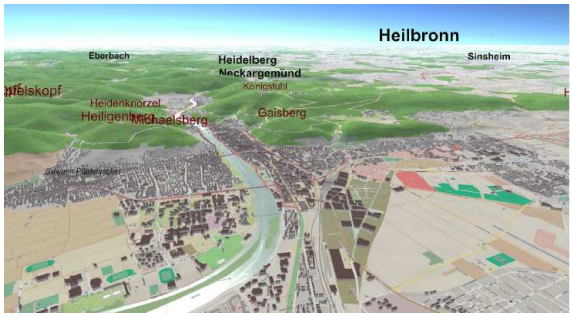
Crowd sourcing






## Open issues

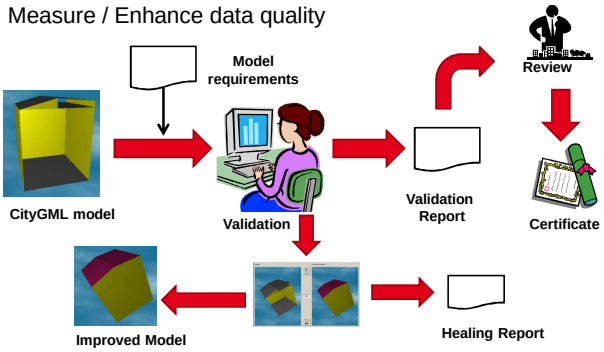
Crowd Sourcing: Open Street Map 3D




Prof. A. Zipf, Universität Heidelberg, http://www.osm3d.de/

## Open issues

Measure / Enhance data quality




http://citydoctor.hft-stuttgart.de/, Förderung durch das BMBF

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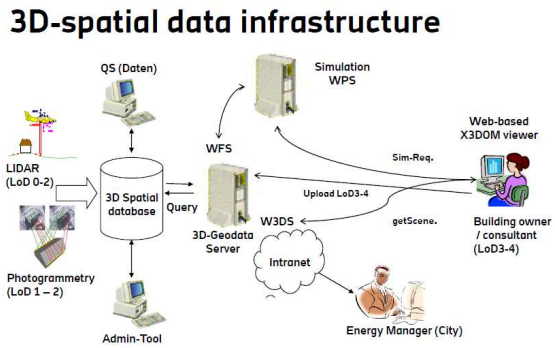
## Standardization: Interfaces

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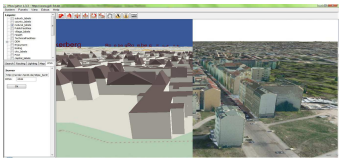
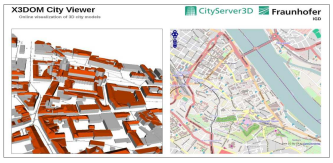
## OGC 3D Portrayal interoperability experiment

Interoperability of OGC drafts W3DS and WVS specifications






http://www.opengeospatial.org/projects/initiatives/3dpie

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## Summary

3D city modeling can already play an essential role for energy planners and municipality manageners

Challanges:

- enhance attribute data (crowd sourcing approach)
- enhance / manage data quality of 3D city models
- develop standard interfaces for 3D spatial data structure
- investigate the use of highly detailed facade geomeotry

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## Hochschule für Technik Stuttgart