What if...?

Urban simulations provide answers to key questions for the future

Saving energy, promoting autonomous driving and improving safety are important goals that many cities share. But how exactly can we achieve them? Geodata-based semantic city models are pointing the way forward. They simulate future scenarios and therefore represent a vital decision-making tool.

Gesamter Artikel (PDF, DE): www.tum.de/faszination-forschung-30

Was wäre, wenn…? Stadtsimulationen beantworten wichtige Zukunftsfragen

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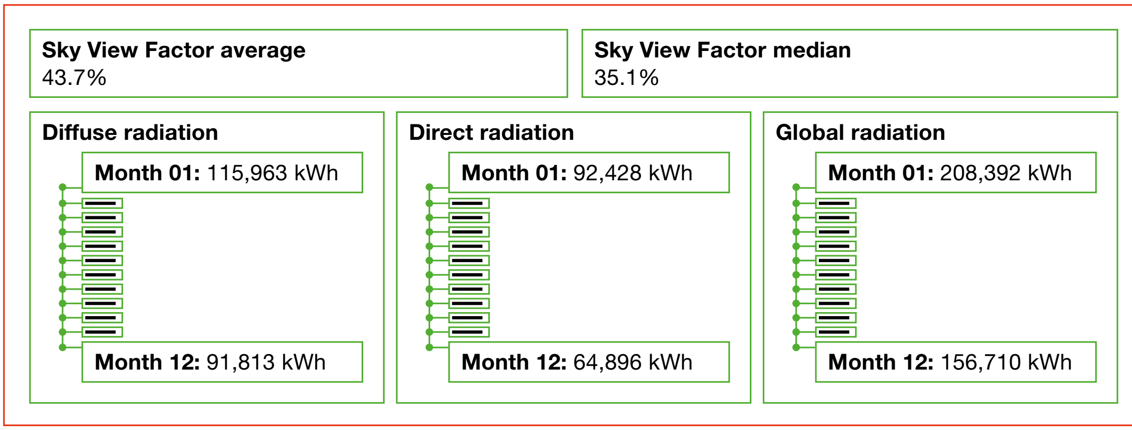
Energie sparen, autonome Fahrzeuge einsetzen und die Sicherheit erhöhen – das sind wichtige Ziele von Städten. Wie lassen sie sich erreichen? Geodatenbasierte, semantische Stadtmodelle weisen den Weg. Prof. Thomas H. Kolbe und sein Team forschen an solchen 3D-Modellen, in die vielfältige Daten einfließen – etwa zu Verkehr, Infrastruktur, Mobilfunkmasten, Gebäudestruktur und Bauvorhaben. Damit berechneten sie beispielsweise den zukünftigen Energieverbrauch der Wohngebäude in München bis 2035 in zwei Szenarien. □

Link
www.asg.ed.tum.de/gis www.3dcitydb.org

Picture credit: edlundsepp (source: Kolbe/TUM)



Semantic 3D city models can be enriched with any data of interest for the actual use case. This model of Munich features diffuse and direct solar energy on the different surfaces of a building, given in monthly and annual totals. The sky view factor (SVF), which indicates the fraction of the sky that is visible, is also computed for the individual surfaces and aggregated for each building.

What if we retrofitted every residential building in Munich with district heating systems and heat pumps to replace oil and gas fired systems? What if domestic hot water supplies relied primarily on solar thermal energy? And what if underfloor heating was installed to replace most radiators?
Well, what would happen? A geodata-based semantic model of Munich can show us by determining potential energy savings based on detailed building information.

More than a visualization: a semantic 3D model

So, where does the information for the model come from? The geodata is provided by public authorities like state surveyors and land registry offices, with further input from topographical maps, aerial photographs and satellite images. Additionally, sensors provide data on traffic flows, the environment and infrastructure. Companies in the telecommunications, transport and real estate sectors can also contribute data, including on cell phone towers, traffic flows and construction projects.
From Berlin to New York to Tokyo, many cities around the world make use of such 3D models. The best way to explain what these models are is to compare them with other systems. The 3D views in Google Maps, for example, rely on a purely visual model that does not contain any semantic data, which means that it does not supply information about any of the buildings it displays. There's no information about usage types like office or residential buildings, how old they are, how many stories they have, and so on. In contrast, geodata-based semantic models include these types of data. "These models are therefore able to collate information from different areas very effectively and simulate scenarios for different questions," says Prof. Thomas H. Kolbe, holder of the Chair of Geoinformatics at TUM, who researches these models.
These 3D models can be used to forecast energy consumption, as the analysis of residential buildings in Munich shows. However, they can also play a vital role in urban planning, transportation planning, safety management and disaster management. "I'm fascinated by these wide-ranging applications," Kolbe explains. "We develop them together with experts in different disciplines and are constantly integrating more data." ▷

Picture credit: ediundsepp

Applications

ranging from urban planning to disaster management

Urban planning
Example: Which areas are suitable for new residential developments?

Required data (RD) from 3D model: All buildings, incl. 3D geometry, usage type, year of construction and number of stories

Traffic planning
Example: Where would autonomous (self-driving) minibuses provide benefits?

RD: Spatial models of roads with precise lane data, traffic density and demand figures, terrain models and building models

Energy planning
Example: Which energy technologies would function efficiently in different areas?

RD: All buildings, incl. 3D geometry, usage type and year of construction

Property management
Example: What is the market value and insurance value of real estate?

RD: All buildings, incl. 3D geometry, usage type, year of construction and number of stories

Safety and disaster management
Example: Which areas are at risk of flooding, a terror attack or a tsunami?

RD: Terrain models, water bodies, all buildings and transport routes in a potentially at-risk area

Ever-improving forecasts – thanks to data collected and harmonized from different disciplines

A research project undertaken by Kolbe and his team is a prime example of how these models can be applied. It examines the intensity of sunlight on Munich's buildings and how it then heats buildings up. South-facing surfaces heat up more than north-facing surfaces – that much is obvious. Temperatures on roofs rise more than those on façades. Trees and chimneys cast shadows, however, while poor air quality reduces insolation. The geodata used in this project has been provided by the Bavarian State Agency for Survey (LDBV); solar irradiance data was calibrated with information procured from NASA, and details of Munich's tree population were obtained using methods developed by the Leibniz Institute of Ecological Urban and Regional Development in Dresden. Kolbe's team integrated all this information to develop a semantic, three-dimensional model of Munich. The end result was a city model highlighting areas in which photovoltaics and solar thermal installations would be worthwhile.

It is essential for collaboration to produce standardized datasets. This is achieved here by the CityGML standard, the development of which was launched and masterminded by Kolbe. It defines how buildings, roads, bridges and even trees should be described in digital terms. This makes models comparable, which, in turn, also makes them cost-efficient. Numerous countries and cities around the world are now providing their 3D models free of charge as CityGML-compliant open data. This enables the integration of more and more data, which, in turn, results in increasingly detailed simulation results. Some urban authorities have already created digital twins – virtual, real-time representations of their cities. So, what if a city aims to become climate-neutral, car-free or safe from natural disasters? These models point the way. ■

Gitta Rohling

Picture credit: ediundsepp

"These models are able to collate information from different areas and simulate scenarios for different questions."

Thomas H. Kolbe

3DCityDB – an open source database for 3D city models and semantic objects

The award-winning 3D City Database is a free geodatabase to store, represent and manage virtual 3D city models. It implements the CityGML standard with semantically rich and multi-scale urban objects facilitating complex analysis tasks, far beyond visualization. 3DCityDB has been in productive and commercial use for more than 14 years in many places around the world as well as in numerous research projects related.

www.3dcitydb.org

Prof. Thomas H. Kolbe

studied computer science at Dortmund University and earned his doctorate at the University of Vechta and the University of Bonn. He worked as a research assistant, and later a senior research assistant, at the University of Bonn. Kolbe then held the Chair of Methods of Geoinformation Science at TU Berlin. Since 2012, he has been the holder of the Chair of Geoinformatics at TUM. Kolbe researches methods that facilitate the spatial, temporal and semantic analysis, modeling and visualization of cities. He is initiator and co-author of CityGML, the international modeling standard to promote the storage and exchange of semantic 3D city models. In 2021, Kolbe became a core member of the Munich Data Science Institute.

A climate-neutral Munich?

Munich has more than 100,000 residential buildings that require heating, cooling and lighting – three processes that generate greenhouse gas emissions. But that's not all: in addition to this direct energy, there's another type – namely embodied energy. This is the energy consumed in the building's construction and the manufacturing, transport, installation and disposal of all the heating, ventilation, air-conditioning, sanitary, electrical, lighting and security systems and technologies.

Energy consumption analyses often fail to take this embodied energy into account. In 2021, Hannes Harter examined this issue in his dissertation, which he completed in cooperation with Kolbe's Chair. Building on a geodata-based semantic model of a city, he developed a method that integrated both direct and embodied energy into its analyses. This was a genuine first. The model contains information about what systems are currently in place for heating, domestic hot water supply and heat exchange. It allows us to answer a number of questions with meaningful figures: How much would it cost to replace existing systems? How much embodied energy would retrofitting involve? Where would energy consumption levels stand afterwards?

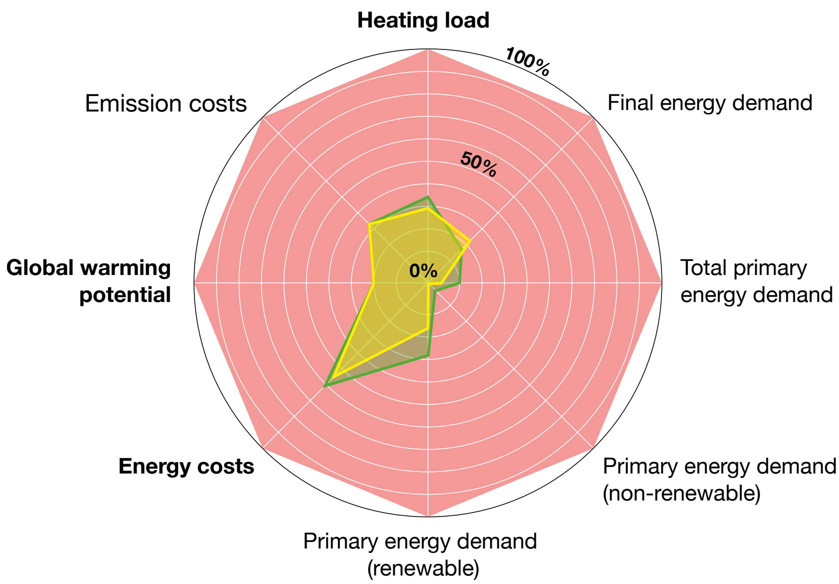
Harter's model estimates the future energy consumption of residential buildings in Munich up to 2035 in two scenarios. Scenario 1 involves using a combination of gas, district heating and heat pumps for domestic heating. In scenario 2, however, gas is removed from the equation entirely. Both scenarios rely exclusively on solar thermal technology for hot water supply, with underfloor heating for heat transfer. The model could also be used to simulate other scenarios.

Now, here's the bad news: when it comes to residential buildings, Munich would not achieve its goal of climate neutrality by 2035. The overhaul required in both scenarios would be so laborious and expensive that it is simply not realistic. And, because buildings require constant repairs and renovation, it is simply not possible for the building sector to become completely climate-neutral. The good news, however, is that retrofitting can save vast amounts of energy. "This shows that we shouldn't stick our heads in the sand – instead, we should use city models to analyze the areas in which retrofitting would be most worthwhile," says Thomas Kolbe.

Picture credit: Juli Eberle; Graphics: ediundsepp, (source: Harter, Willenborg, Lang, Kolbe (2023): Climate-neutral municipal building stock - life cycle assessment of large residential building stocks based on semantic 3D city models, Energy and Buildings, Vol. 292. https://doi.org/10.1016/j.enbuild.2023.113141)

What if…

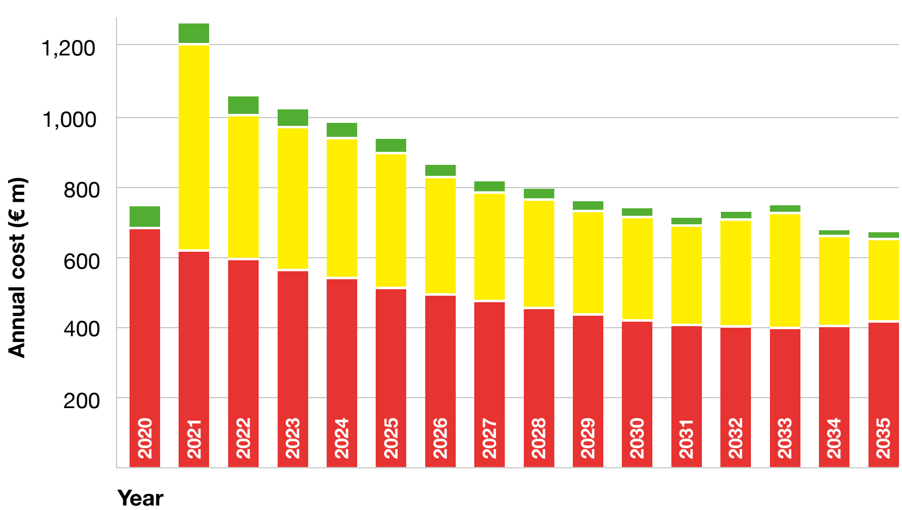
all residential buildings in Munich were given an energy overhaul?



Status quo: Heating energy from gas (70%), oil (20%) and district heating (10%)

Scenario 1: Heating energy from heat pumps (70%; mainly powered with renewable energy), gas (20%) and district heating (10%); warm water: solar thermal; 100% underfloor heating

Scenario 2: Like scenario 1, but heating based on district heating (80%, of which 90% is provided by renewable sources) and heat pumps (20%)



Emission costs

Cost of embedded energy for technical building systems

Heating and warm water costs

Energy and emissions costs per year if all residential buildings in Munich are overhauled between 2020 and 2035 to meet scenario 1. Substantial costs remain for direct and embedded energy and for emissions, even after the overhaul is finished. (Initial emissions cost €25/t CO_2e; annual rise in energy and emission costs 5%; annual rise in construction costs 2%).