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messages from residents now. Otherwise, the barrage of messages these days would be impossible to handle. These stations of course regularly register tremors due to traffic or building activities. For example, on the afternoon of Saturday, 25 August 2012, a tremor was registered by the Austrian Seismological Service that was clearly not caused by an earthquake. With the help of the Viennese monitoring network, it was possible to pinpoint the event in Freudenau. It turned out to be a powerful explosion of an aircraft bomb from World War II. The Seismological Service subsequently received dozens of reports via the Internet from the 1st, 2nd, 3rd, 4th, 10th, 11th and 22nd districts.

The data from the stations in Vienna can be used to quickly estimate the extent of the damage. The results are important not just for earthquake safety in Vienna. Measurements and analyses like these are performed in numerous big cities with similar seismic activity. The measurement data and analyses have already served as an important basis for responding to numerous enquiries from the construction sector and from civil protection and disaster control services with regard to emergency plans and crisis management. They also serve as the foundation for matters of urban planning such as renovation concepts for older buildings in Vienna, which are known to be particularly susceptible to damage.

The measurement results can now be compared with the reports about the effects of tremors by people living in the districts in various buildings and on various floors. This makes it possible to compare the effects and the actual measurement data of ground motions. In addition, the recordings can be analysed used to assess the effects of the ground on structures.

The seismic monitoring network is therefore an important aid in recording the dynamic stress on buildings during an earthquake. In a city that serves as an international business hub, a location for international organisations, a cultural metropolis and a popular tourist destination, a monitoring network plays an important role in meeting international safety and security requirements.

Conclusions

As history has shown, the capital of Vienna has been subject to seismic vibrations on numerous occasions over the past 1,000 years. Although Vienna was never the epicentre of any of these tectonic quakes, the effects were sometimes strong enough to cause serious damage to buildings, which is why a great deal of attention is paid to earthquake-resistant construction methods. In addition, other causes of tremors are now recorded that are also of interest. After all, who wants to be "shaken" without knowing why or being aware of the consequences?

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Urban mining and final sinks: key elements of a smart city

PAUL H. BRUNNER, ULRICH KRAL

The metabolism of modern cities is incredibly large. In Vienna, for example, each inhabitant goes through roughly 200 metric tons of materials a year. For the city as a whole, the annual volume is roughly 340 million metric tons. This "urban metabolism" not only places high demands on the supply but also poses a daunting challenge when it comes to the disposal of exhaust air, sewage and waste.

The city as a flow reactor

On the input side, the availability of resources must be guaranteed, and on the output side, water, soil and air must be protected in order to maintain the most important service functions of the environment (primary production, mineralisation, material cycles, biodiversity).

In terms of the volume consumed, the most important goods are roughly 150 t/E.a of (drinking) water followed by 36 t/E.a of air. The remaining goods such as construction materials (gravel, sand, stones) for networks (traffic, water/sewage, energy, information), metals, energy sources, vehicles, food and other products make up an additional 20 t/E.a. The largest share of these goods is imported, which means that Vienna is very dependent on the regional hinterland (for water and construction materials) and the global hinterland (for air, fossil fuels and metals). Out of a total of roughly 200 metric tons per inhabitant, more than 95 per cent are exported again, usually as sewage and exhaust air. Solid waste comes to roughly three metric tons per inhabitant and year, the majority of which is construction waste. The percentage of all goods recirculated in anthropogenic cycles is low. In other words, Vienna's material flow is predominantly linear – particularly because of the large portion of water and air. One notable aspect is the recycling of waste: At the moment, roughly 50 per cent of solid waste is recycled as materials, and the rest is thermally recycled.

The goods used in cities comprise a wide variety of materials (chemical elements and compounds). Roughly 30,000 chemical compounds are used daily in large volumes (metric tons). The total number of known materials comes to several million, and an additional million is added to this each year. These materials, which are only used in small amounts sometimes, play an important role in determining the characteristics and functions of modern goods: They enable new applications in information and energy technology, they increase the life cycle by protecting against light, UV rays and micro-organisms, they prevent hazards, for example, by increasing fire resistance, or they improve product features by increasing durability and impact resistance and preventing corrosion. However, some of the chemical compounds that are used can endanger human health: They are toxic, carcinogenic, toxic for reproduction or affect the hormones. Others are of ecotoxicological concern and have a negative influence on soil fertility or biodiversity.

The metabolism of modern metropolises is incredibly large.

It is therefore necessary to examine the urban metabolism to see where problematic material flows are being directed and whether water, soil and air are being polluted. In any case, there need to be filter systems between the city and the environment that can reliably either convert the pollutants that leave the "flow reactor" of the city into harmless materials or deposit them in secure "final sinks". Waste incineration plants and sewage treatment plants represent filter systems like this. Both are capable of breaking down and converting pollutants. Thermal plants in particular, which can destroy and mineralise organic pollutants at high temperatures – in other words, break them down into CO_2, H_2O and other basic molecules – are an essential part of a smart city. Due to the large existing volume of persistent organic pollutants used in the past, thermal plants are indispensable – even in the case of an active prevention strategy.

The city as a store of raw materials

Each year, roughly four to ten metric tons of imported materials per inhabitant are added to the City of Vienna's stocks. Each resident of Vienna already has a stock of roughly 350 metric tons of materials. These material stocks consist mainly of long-lasting infrastructure (structures such as residential, service and industrial buildings, roads and other networks) and consumer goods (cars, furniture, etc.). They are growing at an average of seven metric tons per year and, at that rate, will double in size in about 50 years.

The significance of these stocks should not be underestimated: On the one hand, the volume of waste will increase in the future (at the end of the life cycle of the products in the stocks), and this waste represents a valuable material resource for the future in terms of urban mining (see, for example, www.urbanmining.at). The large volumes of building materials used in the second half of the 20th century for urban infrastructure are starting to end up in waste management now and – as a result of growth – this volume will increase in the future. They represent great potential for the future as secondary resources.

Anthropogenic stocks are full and will soon be available as secondary resources.

On the other hand, these material stocks also represent a kind of mortgage: Their composition will be relevant for energy demand and environmental protection in the coming years. For example, huge efforts are needed to adapt buildings in the city in order to reduce the CO_2 emissions from heating and air conditioning to an environmentally safe level (through thermal insulation, passive sun protection, etc.). In addition, the material stocks in transport systems do not correspond to low-energy and low-CO_2 economic practices and will have to be adapted to meet the problem of climate change in the coming decades.

As described earlier, these stocks also represent significant hazard potential. They contain many substances that are now considered toxic – substances that were used in large volumes in the past but are no longer permitted. These include polychlorinated biphenyls (PCB) in electrical devices and joint compounds, halocarbon compounds in building materials, cadmium in long-lasting polyvinyl chloride (PVC) and brominated flame retardants in plastics. These toxic substances not only need to be disposed of in an environmentally friendly way. They also need to be kept out of cycles. Establishing clean cycles particularly for long-lasting, highly stabilised plastics, but also for scrap metals and matured timbers, represents a big challenge. This problem will increase further in the future because the composition of consumer goods has become more and more varied and complex in recent decades. There are no signs that this trend will reverse in the future.

"Urban mining" as a long-term source of raw materials

The retrieval of metals, construction waste, plastics and additional materials from stocks of anthropogenic materials is sometimes referred to as "urban mining". Recently, landfills have also been incorporated into considerations about the recycling of raw materials. What does urban mining mean? Urban mining is much more than simply recycling. The aim is to achieve sustainable, clean cycles through the long-term, multiple and pollutant-free recycling of materials after their economic and technical life cycle is over. To achieve this goal, urban mining must be defined as the systematic, targeted planning, design and reuse of anthropogenic material stocks for the purpose of the optimal conservation of resources and long-term environmental protection. The main anthropogenic material stocks are in buildings, infrastructure and consumer goods, but urban mining can also exploit landfills and spoil tips from mining. However, rough estimates show that the material stocks in the latter are smaller than in the former. Urban mining is therefore a necessary strategy for a smart city and comprises the following four pillars:

- **Design for urban mining**
  Designing products, processes and systems with long-term reuse in mind: Today's goods are complex mixes of materials. They are often difficult to separate into individual mate-

rials and recirculate efficiently. In the future, aspects of a second and multiple material cycle will be considered during design and integrated into products. The aim is to create goods that can easily – in other words, without the use of much energy and material resources – be converted into uniform, reusable secondary raw materials.

- **Urban prospecting**
  Like conventional mining, urban mining also requires methods for determining the location of and potential for breaking down resources. In mining, geological, geophysical and geochemical methods of prospecting are used to explore for new deposits. In urban mining, we also need methods for finding and evaluating urban deposits. At the moment, prospecting for urban resources is still in a very early stage. In order to make urban mining profitable compared to primary mining, it is necessary to investigate and apply methods of prospecting urban raw materials. The result of methods like these is information about the volume, type, association and location of secondary resources – all prerequisites for successful urban mining.

- **Resource inventory**
  At the moment, the whereabouts of materials in a city are usually unknown and can only be roughly estimated. Particularly in the case of goods with a long life cycle, information about the type, volume and composition of the goods tends to be missing at the end of the life cycle. This also makes it impossible to predict when, where and in what volume materials will be available for urban mining in a city. However, information about materials was available at the time that buildings were constructed, for example, in the form of specifications – it was just not retained. In the future, it will be essential to systematically preserve information about materials or – if it is not available – to find it out, manage it and provide it to the corresponding users for recycling at the end of the life cycle. One idea would be a product passport for individual buildings ("building passport") and a resource inventory at the local and regional level. They would provide a smart city with information about which materials are available in which volumes, concentrations and associations, and information about when these will reach the end of their economic life cycle.

- **State-of-the-art technology for separation and recovery**
  Other prerequisites are technologies for separating the existing secondary resources into valuable materials and into worthless materials and pollutants in an economical way. A big gap exists here. It will be necessary to develop new high-tech processes that can separate complex compounds and make them available as secondary materials. This will require the development of physical, physical-chemical and also chemical processes that allow for the extraction of valuable, clean products without having to use much materials or energy. The long-term, environmentally sound disposal of residues will therefore require secure "final sinks" (for example, underground repositories).

The management of secondary raw materials from anthropogenic stocks based on these four pillars goes far beyond simple recycling and is

rightly referred to as urban mining. Like with traditional mining, it will take a while to develop new approaches and technologies for the new mining of cities and to implement them. But time is of the essence: Anthropogenic stocks are full and will soon be available as secondary resources. It is important for smart cities to seize these new opportunities.

Smart cities cannot survive without final sinks

Urban mining makes it possible to reuse valuable materials. However, the question remains as to what will happen to the materials that can or should not be recycled – either because they are available in too small of quantities and concentrations, because they are mixed with other materials and cannot be recovered under economical/ecological conditions or because they must be removed from the cycle for health or ecological reasons. The question is therefore what to do with

- heavy metals in consumer goods, brake linings and roof surfaces,
- organic compounds in flame retardants, plasticisers and foams, and nutrient matter in used or converted biomass.

All of these material flows are released in cities and pose logistical challenges and technical obstacles for residents as well as city administrators.

Future-oriented disposal concepts in smart cities envisage recirculation as well as controlled disposal in "sinks" and "final sinks". However, sinks and final sinks are limited in their intake capacity and must therefore be managed appropriately and in a forward-looking manner. But what are these sinks and final sinks at the end of the urban metabolism?

"Sinks" are limited in their intake capacity.

Generally, a sink refers to the opposite of a source. A sink is used to store materials or to get rid of them (by converting them into other materials, for example, into carbon dioxide and water through incineration). A city's soil, for instance, serves as a sink for powder emissions from car traffic. A purification plant can be used serves as a sink for urban sewage, a compost plant as a sink for green waste and a landfill functions as a sink for non-recyclable waste.

Materials often remain in sinks for short to medium periods of time and are transported on through natural processes or anthropogenic processes. For example, a significant portion of carbon, nitrogen and salts is mobilised in household waste landfills that serve as sinks and, depending on the treatment, travels on to a sewage treatment plant or into bodies of water via leachate.

Final sinks are a special case. Materials can stay in them for a very long period of time – in any case, more than ten thousand years. If a substance can stay in a sink this long, it will only be transported out extremely slowly. In other words, it is highly immobile and will most likely not cause any damage outside of the final sink. If a substance is destroyed by a process (for example, the incineration of phenol into carbon dioxide and water), this process also represents a final sink for the material. Waste incineration is therefore the final sink for many organic pollutants (but also for health-damaging microorganisms).

Both types of final sink are necessary in order to store pollutants in an environmentally sound way. For inorganic materials that cannot be destroyed but only converted, these long-term, "definitive" stores are necessary for sealing materials off from the environment in a safe way and for geological periods. At the moment, particularly salt mines and other geological formations that were sealed off from the water supply for thousands of years are considered safe final sinks.

A final sink can therefore be seen as the very end of a specific material flow. Special attention should be paid to the difference between sinks, in which materials stay for just a limited amount of time, and final sinks, in which they stay virtually forever: Although the waste incineration plant is a final sink for organic compounds, for metals, it can only be considered a sink. Due to their material properties, metals are not destroyed here but end up in the combustion products, which – if they contain heavy metals like flue gas cleaning products – must primarily be disposed of in the last sink of underground repositories. In other words, thermal treatment only represents a sink for metals on the way to their indispensable last sink.

The task for the future is to achieve "clean cycles" and "environmentally safe final sinks".

The purpose of every urban disposal concept is to ultimately completely transfer all non-recyclable waste flows (emissions, liquid and solid waste) into a final sink without any bypasses. This ensures that pollutants are managed in an environmentally sound way.

On the one hand, history has shown that people create final sinks artificially as soon as natural final sinks are overloaded and negative effects are observed (for example, the catalytic converter of a car as the final sink for nitrogen oxides from exhaust emissions or biological sewage purification as the final sink for the removal of degradable organic compounds). This increases the capacity of sinks in order to meet environmental quality standards. On the other hand, final sinks have not been found for all waste flows, cannot be controlled without bypasses or cannot be created in time (greenhouse gases, halocarbon compounds, DDT, heavy metals in car brake lining, etc.). No matter what, smart cities must base the use of material resources on the capacity of sinks and final sinks. In service-oriented cities like Vienna, for example, it is important to reduce carbon emissions from fossil fuels through effective measures so that the atmosphere as a sink does not become overloaded. Or to examine heavy metal deposits in the sink of the city's soil and to resort to source-oriented measures in the case of overuse.

Questions about final sinks have neither been asked nor answered

For a city, the factors of clean cycles and environmentally safe final sinks are decisive and indispensable for ensuring that resources are used in an environmentally friendly way and in coordination with the existing sink capacities over the long term. If we want the smart-city concept to have a sustainable, broad basis, we need last sinks not only for CO_2 and CH_4 from fossil fuel carbon emissions (energy supply, traffic, etc.), but also for other essential materials such as nutrient matter (nitrogen, phosphorous), heavy metals and organic compounds. So far, comprehensive questions about final sinks have neither been asked nor answered. Final sinks are a necessary part of smart cities, without which their long-term survival is not guaranteed.

Conclusion

The law of conservation of mass also applies to cities: The things that are imported into cities can either accumulate in the city or must be exported sooner or later. The future task for smart cities will be to profitably reuse the large volumes of materials in a city after their life cycle is over through clean cycles and also to dispose of pollutants in an environmentally sound way in safe final sinks. Cities that see this as not merely a recycling and disposal task but as a design and planning process will gain a significant economic and ecological advantage over the long term as true smart cities.

Source

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