Concrete Solutions for Climate Resilient Built Environments

Claudia Dankl, Sebastian Spaun

(Dipl.-Ing. Claudia Dankl, Association of the Austrian Cement Industry, Franz-Grill-Straße 9, 1030 Vienna, dankl@zement.at)
(Dipl.-Ing. Sebastian Spaun, Association of the Austrian Cement Industry, Franz-Grill-Straße 9, 1030 Vienna, dankl@zement.at)

1 ABSTRACT

Concrete is the most widely used building material worldwide. That is one reason why it is very often associated with high CO_2 emissions, although on the base of mass [kg] or volume [m³], the specific CO_2 footprint of concrete is relatively low compared to other building materials. This is in particular true for modern cement and concrete. In 2022, the Austrian Cement Industry published its roadmap towards CO_2 neutral production of cement. Various measures are foreseen and projects have already been undertaken to move the CO_2 footprint of cement in Austria towards zero.

This applies to all types of cement, regardless of the application – and there are many of them. Every construction project requires a special type of concrete; there are different mix designs for buildings, civil engineering, and specialised applications. Water-impermeable concrete is required for so-called “white tanks”, whereas in urban planning – in view of increasingly hot summers and heavy rainfall – the opposite, water-permeable concrete, is advantageous in terms of infiltration capacity. This can take the form of “drain concrete” or concrete paving stones, which must be laid in such a way that infiltration can take place via the paving joints.

Infiltration-capable surfaces, trees and plants are essential for the resilience and important design elements of our cities. Innovative approaches in the use of concrete and holistic planning can make cities more ecological, liveable, and sustainable, Therefore, such approaches have an important function as instruments for adapting to climate change. However, concrete can be used innovatively not only for “green infrastructure”, but also for “blue infrastructure”, the use of water in urban spaces.

The “sponge city” is a concept designed to help urban trees gain more vitality. The underground construction is crucial for the sponge city effect: the concept gives the trees more room to grow roots below the paved surface in interconnected gravel bodies. The substrate acts like a sponge: on the one hand, the trees are supplied with water and, on the other, water is stored and does not flow unused into the sewage system. A high infiltration rate is also important on the paved surfaces. The concrete paving stones play a central role in the functioning of the sponge city concept – they provide more climate protection, a pleasant atmosphere, and thus counteract the urban heat island effect, Due to their light surface and a higher albedo of concrete compared to asphalt, they can contribute to a more pleasant micro-climate in urban areas.

In Austria, the sponge city concept has been successfully implemented in several projects: In Vienna, the first sponge city project was in Pelzgasse in Vienna’s city district of Rudolfsheim-Fünfhaus. In addition to the paving of the areas, further design measures were implemented to make the public space more attractive.. The project is being scientifically monitored by the University of Natural Resources and Life Sciences, the BOKU Wien.

In Vienna, the sponge city concept was also implemented near the “Bildungscampus Aspern Nord”, where around 10,000 m2 of concrete block pavement were built in the neighbourhood “Am Seebogen”. The sponge city concept has also been successfully realised in several small and medium-sized towns in Lower and Upper Austria, some of which are presented below. A video series by the Lower Austrian Association of Municipalities shows best practice from the cities Amstetten, Lanzenkirchen, and Tulln.

The presentation ranges from the production of CO_2-reduced cement in Austria to the sustainable use of concrete for planning and design of innovative open spaces in urban areas following the sponge city principle, which enables adaptation to climate change.

2 CEMENT AND CONCRETE – CONTRIBUTION TO SUSTAINABILITY

2.1 The Austrian cement industry's roadmap to CO_2 neutrality

The Austrian cement industry is committed to the Paris climate targets. In 2022, based on the production figures from 2020, the roadmap outlined a way in which the production of cement in Austria can be climate-neutral by 2050 (Spaun et al. 2022). The 5C strategy of the European cement association Cembureau serves as the basis for the Austrian cement industry's roadmap. The 5Cs as focus areas for measures are: Clinker, Cement, Concrete, Carbonation and Construction (Cembureau 2020). These five areas are briefly described below and their implementation in the roadmap of the Austrian Association of the Cement Industry VÖZ is explained in more detail.

2.1.1 Clinker

Clinker is the most important component in the production of Portland cement. It is produced from the raw materials lime, clay and marl in a rotary kiln at 1,450 degrees Celsius. The major part of CO2 emissions in cement production arise from this process: around one third originates from the fuels, and around two thirds are geogenic emissions, as CO2 is released from the limestone by turning calcium carbonate into calcium oxide. By reducing the proportion of clinker in cement significant contribution to reducing emissions can be made.

2.1.2 Cement

The production of one tonne of cement in Austria released 503 kg of CO_2 in 2023 (VÖZ 2024). This makes Austria one of the countries with the lowest specific CO_2 footprint of cement worldwide. The good values are based on the high efficiency of Austrian cement plants and on a high share of secondary materials: alternative raw materials, alternative fuels as well as alternative additives. The main additives used are granulated blast furnace slag and fly ash, which are residual materials from other industries that will no longer be available to the usual extent in the coming years or decades. Research is therefore being carried out into new additives, e.g. calcined clays showing great promise. In line with the roadmap, the Austrian cement industry is researching new types of cement that offer the same performance with less clinker. So-called CEM II/C cements have already been developed and are ready for use thanks to technical approvals.

2.1.3 Concrete

The Austrian cement industry's CO_2 roadmap sees the potential for reducing CO_2 emissions of concrete primarily in reducing the proportion of clinker or cement used in the concrete, i.e. in the concrete mix design. Cement and concrete are therefore shown together in one column in the roadmap.

2.1.4 Carbonation

Carbonation is a process in which concrete reabsorbs CO_2 from the ambient air on the air-exposed surface. In chemical terms, this process is to a certain extent the reverse of the process of calcination of the limestone, where the CO_2 is emitted when the clinker is burnt. Carbonation can be accelerated as part of concrete recycling, the crushed concrete charged with CO_2 can be reused as a recycling fraction in the aggregate, or the fines can be used as a component of cement. An important approach to combining circular economy and decarbonization of the cement and concrete sector.

2.1.5 Construction

The area of construction itself lies outside the sphere of influence of cement production, but holds potential for reducing the CO_2 footprint on many levels. Constructions can be made leaner and more efficient, and the use of less material also reduces CO_2 emissions.

In addition, technologies such as building component activation can help to reduce the energy required for heating and cooling buildings and thus again help reducing CO_2 emissions, especially during building operation.

2.1.6 CCUS

In the Cembureau's 5C strategy, carbon capture technology (CC) is seen as part of clinker production. The Austrian cement industry identifies CCUS as a separate pillar, which primarily represents the geogenic emissions that arise during the calcination of limestone. These emissions must be captured and then either stored (Carbon Capture and Storage CCS) or used (Carbon Capture and Utilization). Both capture and further utilization are quite energy-intensive processes, which is why the potential of the other levers should be exploited first.

2.2 Sustainable use of concrete

Concrete is the most widely used material in the world, thanks to properties such as load-bearing capacity, durability, performance and great flexibility in use. Concrete is fire-resistant and its mass contributes to sound insulation as well as to the efficient operation of buildings for heating and cooling. A major advantage of concrete in terms of social sustainability is its affordability.

Another strength of cement and concrete is a very efficient use of resources and contributions to circular economy. Concrete is a man-made stone. Like a stone, concrete can therefore be reused and recycled at the end of its service life. It can replace primary material in fill or be crushed and reused as recycled aggregate for the production of concrete. Precast concrete can be separated again and reused as a whole if the joining technology has been designed accordingly.

Concrete is sustainable if it is well planned and used efficiently according to its strengths – from the choice of the right mix design to integration into well thought-out structural concepts and the efficient use of materials. Many projects are already demonstrating that this is possible. The positive properties for resilient urban design are discussed in the following chapter using the concept of the sponge city and the example of water retention.

3 CONCRETE FOR RESILIENT URBAN PLANNING

Green spaces, parks and squares are important design elements, especially in cities, and at the same time they have an important function as instruments for adapting to climate change in times of climate crisis. Trees and plants contribute positively to the microclimate in cities through their cooling effect. In urban areas in particular, however, surfaces also need to be paved, as they need to be accessible in bad weather conditions or for emergencies such as fire or rescue operations. Concrete ensures such trafficability and, with its light-colored surface, has clear strengths compared to other materials: Concrete has a high albedo and heats up less than dark paved surfaces (EU PAVE). Designed in the form of paving stones or as so-called drainage concrete with continuous cavities, surfaces can be paved with concrete and still be made permeable. The urban microclimate can be positively influenced by the retention of water and, as a result, more evaporation.

The sponge city concept can help urban trees to achieve greater vitality. The decisive factor is the underground construction: below the paved surface, the trees are given more space for root formation in interconnected gravel bodies. The substrate acts like a sponge: on the one hand, the trees are supplied with water and, on the other, water is stored and does not flow unused into the sewer system. The paved surfaces above these bodies must allow a high level of infiltration, which is why concrete paving stones play a central role in the functioning of the sponge city principle.

3.1 The sponge city principle – examples in Vienna

One of the first sponge city projects in Vienna was implemented in Pelzgasse in Rudolfsheim, it has been opened as “cool street” in summer 2020. The street and sidewalk were raised to the same level and designed to be barrier-free with around 1,700 square meters of concrete paving stones. In addition to the tree planting, further improvements were implemented: new benches, a drinking hydrant, a play table and a water feature in the form of ground-level spray nozzles. The project is being scientifically supported by the University of Natural Resources and Life Sciences. (Gary 2022, p. 27)

In Seestadt Aspern, the sponge city was implemented in the “Am Seebogen” district at the Bildungscampus Nord, where around 10,000 square meters of road surface were paved with concrete blocks. There is a layer of coarse-grained gravel and water-retaining materials underneath to care for the trees. The trees are planted in the tree grates as usual, but have direct contact with the gravel layers and can root through them. The following graphic by 3:0 Landschaftsarchitekten, also involved in implementing the sponge city in Aspern, shows how the system works.

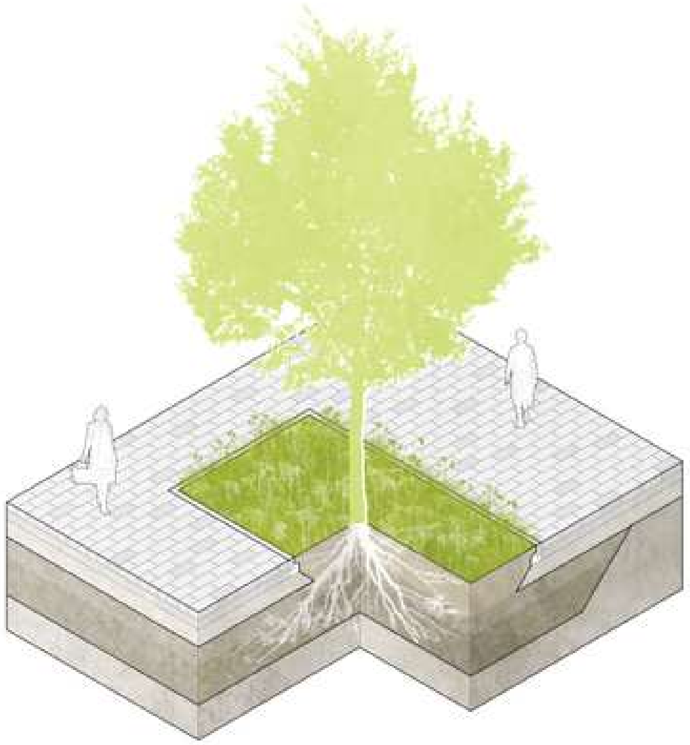

Fig. 1: Sponge City principle shown around and underneath a tree. (Source: 3:0 Landschaftsarchitektur)

Numerous other sponge city projects have already been and are being implemented in Vienna. One current project is Bruno-Marek-Allee in the Nordbahnhof district, which is designed as a “climate boulevard” with green spaces, trees, unsealed surfaces and wide sidewalks for a relaxed stroll.

3.2 The sponge city principle in medium-sized cities

Small cities are also affected by heat and drought. Greening and the unsealing of surfaces also help to counteract overheating here. The sponge city principle enables urban trees to survive even during long periods of heat and drought. At the same time, it relieves the burden on the sewage system during heavy rainfalls and thus prevents flooding.

A current example of climate-friendly redesign is the city of Tulln in Lower Austria: following a comprehensive public participation process and a referendum in 2021, Nibelungenplatz in Tulln was extensively redesigned from May 2023 to June 2024. Before the redesign, the few trees on Nibelungenplatz offered hardly any shade and 80 percent of the total area was not permeable – which led to temperatures of more than 40 degrees Celsius in summer. In order to naturally shade as much of the square as possible, large trees were planted according to the sponge city principle: Thanks to the large root space and well thought-out road base, rainwater can be stored, allowing large-crowned, healthy trees to develop. After the redesign, 70 percent of the total area are open to infiltration (green areas, gravel, etc.) and an additional 23 percent of the total area are permeable (paving). The paving is done with light-coloured stones. The choice of paving stones and their sizes depends on the type of use of the respective area. For example, ecological paving with high permeability and green joints is used on the car parking areas (Stadtgemeinde Tulln 2025).

The sponge city principle had already been implemented in several municipalities in Lower Austria before, for example on the main square in Lanzenkirchen, where 30 trees have been planted. Since then, heavy rainfalls in the municipality remained without consequences. Videos on the YouTube channel of the NÖ Gemeindebund, the Lower Austrian Association of Municipalities, show relevant stakeholders from the municipalities of Amstetten, Tulln and Lanzenkirchen reporting on their experiences and the benefits of the sponge city principle, like inner-city infiltration areas, unsealing of villages and towns, sustainable use of rainwater and promotion of biodiversity.

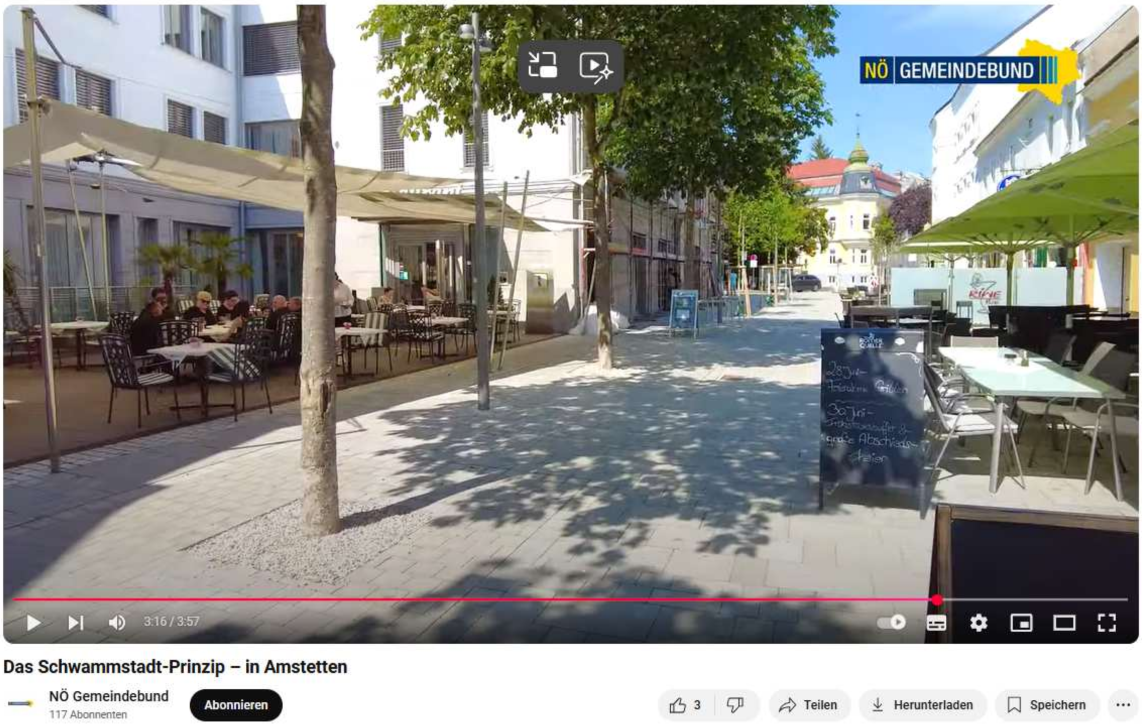

Fig. 2: Snapshot from the YouTube video of the Sponge City in Amstetten, Lower Austria (Source: https://www.youtube.com/watch?v=7ij4FUDjUIM).

3.3 Water storage

In addition to being used for surface pavings, concrete is also used underground in connection with the water management. The sewer system in Vienna is relieved during heavy rainfall events with three large concrete storage basins. These protect the city from flooding, while the retention of the water and its subsequent purification in the sewage treatment plant also protects nature. The concrete storage basin in Simmering, was opened in 2016 and it is 90 meters long, 45 meters wide and seven meters deep. A sports ground is located on the reservoir, which is situated at a topographical low point in the district and was the ideal location for the construction of the reservoir. Directly below the main pitch, up to 28.5 million liters of water are temporarily stored during rainy weather. The Gelbe Haide reservoir near the Inzersdorf freeway junction can hold around 10 million liters of water. The reservoir absorbs the first flush of rain and is considered a highly efficient climate change adaptation measure. After construction, the structure was covered with a six-metre-thick layer of soil from the excavation. A 4,500 square meter green area was created on top. The green roof ensures a pleasant microclimate. This storage basin is 70 by 40 meters in size. The “floodgates” are only opened after the heavy rain has stopped and the water can flow through the sewer system to the sewage treatment plant in Simmering (Gary 2022).

3.4 Concrete for vertical greening

Planting can also contribute to mitigating the urban heat island effect in buildings in a simple but very effective way: plants photosynthesize with the help of solar energy, releasing moisture and thus cooling themselves and their surroundings. The greening of buildings helps to integrate nature into urban living spaces. Concrete is a material that is well suited to planting, as it is less sensitive than other building materials to moisture and other “biological attacks”, i.e. damage that the roots of plants can do. The “Bosco verticale” in Milan by Stefano Boeri is a vivid and well-known example of how concrete structures can be turned into a green landscape in innovative urban and neighborhood planning. At “Bosco verticale” two towers are housing a total of 800 trees, providing an amount of vegetation equivalent to 30,000 square meters of woodland and undergrowth, concentrated on 3,000 square meters of urban surface (Stefano Boeri Architetti).

4 CONCLUSION

Topics and examples in this contribution range from the sustainable production of CO2-reduced cement in Austria to the sustainable use of concrete in urban areas. Innovative planning with the sponge city principle is shown, as well as other examples of how concrete can contribute to climate change adaptation in cities. Concrete can be used above and below ground, thus contributing to the efficient use of space, which is particularly important where space is scarce. A best-practice example for an efficient use of space is an underground water storage basin in Vienna, which provides relief during heavy rainfall events and at the same time offers a sports field on its surface for leisure activities – an excellent example of stacked multifunctional surfaces. It is important to assess building materials holistically over their entire life cycle. Cement and concrete offer numerous advantages in terms of greening and the water balance in cities, putting other building materials in the shade.

5 REFERENCES

CEMBUREAU: The 5C Approach: Call for a concerted effort. https://lowcarboneconomy.cembureau.eu/5-years-on/the-5c-approach/ (accessed 24.02.2025).
EUPAVE: Factsheet “High Albedo”. Brussels, 2020. https://www.eupave.eu/resources/how-high-albedo-contributes-to-reduction-of-carbon-emissions-from-road-transport/ (accessed 24.02.2025)
GARY, Gisela: Einblick in Wiens Unterwelt. In: Zement und Beton, Issue 2, pp.31–35, Vienna, 2022.
GARY, Gisela: Erfolgreich gegen Hitzeinseln. In: Zement und Beton, Issue 2, pp. 26-27. Vienna, 2022.
SPAUN Sebastian, Bauer Cornelia, Dankl Claudia, Friedle Rupert, Papsch Felix: Wie Was Wenn. Roadmap zur CO2-Neutralität der österreichischen Zementindustrie bis 2050. Vienna, 2022.
Stadtgemeinde Amstetten: In Amstetten entsteht NÖs größte Schwammstadt. https://www.amstetten.at/aktuelles/in-amstetten-entsteht-noes-groesste-schwammstadt/ (accessed 17.02.2025)
Stadtgemeinde Tulln: Das war der Prozess zur Umgestaltung des Nibelungenplatzes. https://www.tulln.at/aktuelles/nibelungenplatz-beteiligungs-und-planungsprozess (accessed 19.02.2025)
Stadt Wien: Europas größtes Kanalbauprojekt in Simmering https://www.wien.gv.at/umwelt/kanal/baustellen/kanal-simmering.html (accessed 23.02.2025)
Stefano Boeri Architetti: Vertical Forest Milan https://www.stefanoboeriarchitetti.net/en/project/vertical-forest/
VÖZ – Vereinigung der Österreichischen Zementindustrie. Kennzahlen 2023. Vienna, 2024. https://www.zement.at/service/archiv/37-2024/459-kennzahlen-der-zementindustrie-2023 (accessed 25.02.2025)
Wien ORF.at: Erste dauerhaft coole Straße eröffnet. https://wien.orf.at/stories/3061237/, (accessed 21.02.2025)
YouTube Videos Sponge City (German only)
Das Schwammstadt-Prinzip – in Amstetten https://www.youtube.com/watch?v=7ij4FUDjUIM
Das Schwammstadt-Prinzip – in Lanzenkirchen https://www.youtube.com/watch?v=nuaqmiKa0Ig,
Das Schwammstadt-Prinizip – in Tulln https://www.youtube.com/watch?v=jlYtIGfOlcI&t=1s