Activity 2.2 – Upscaling and testing of green and bio-concrete products

D.2.2.4 Report on Implementation of New Circular Products as a Solution

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1. Introduction

As part of Activity 2.2 – Upscaling and testing of green and bio-concrete products, **D.2.2.4 - "Report on Implementation of New Circular Products as a Solution"** focuses on the validation of innovative, circular building materials under real construction conditions.

The objective was to transfer previously developed laboratory materials into pilot-scale applications and to evaluate their performance, durability, and applicability on-site.

In-situ tests were conducted by:

- PP3 (ZAG) in Slovenia – installation and acoustic testing of Hempstatic hempcrete panels in a pilot building;
- PP14 (HM) in Germany – implementation of concrete with 100 % recycled aggregates in building components at the "Campus Ost (CaO)" pilot site.

Detailed results and monitoring data will be presented in the final pilot project report (Activity A.2.5).

2. Hempcrete Panels (PP3, Hempstatic)

The **hempcrete panels** were developed in collaboration with the start-up Hempstatic. They were tested not only under laboratory conditions also and in a pilot project at Partner PP3 Nigrad in Dogoše near Maribor, Slovenia. The pilot testing was conducted by ZAG (PP1) and focused on acoustic performance, fire behaviour, and indoor air quality.

The objective was to verify the acoustic efficiency and environmental performance of the panels under real building conditions and to compare the results with laboratory reference data.

2.1. Test Setup and Conditions

2.1.1. Test Location

The measurements were carried out in two large rooms in the two-storey pilot building, which is located on a gravel and construction waste landfill site in Maribor.

The room on the ground floor is typically used as a cafeteria and meeting room, while the room on the upper floor serves as a conference room. Both rooms are connected by an open staircase, meaning that they are not acoustically separated from each other. Although this does not fully comply with the ISO 354 standard, the rooms were considered suitable for investigating the sound absorption behaviour of the panels on site.

Room volume:

- Ground floor: 184 m^3
- First floor: 154 m^3

The rooms were poorly furnished, ensuring consistent acoustic conditions for both measurement phases (before and after installation).

2.1.2. Hempcrete Panels

The test specimens were 500 × 500 mm panels, 40 mm thick, made from hemp shives and lime. The panels were glued to the walls. A total of 38 elements (with a total area of 9.5 m²) were installed on the ground floor, and 18 elements (with a total area of 4.5 m²) were installed on the first floor. Figure 1 shows the installed hempcrete panels.

Laboratory tests of the same product, carried out in accordance with ISO 354, were used as a reference for the pilot tests.

Figure 1: Installed test specimens; top: ground floor with panels mounted individually; bottom-left: 1st floor panels mounted in batches; bottom-right: panel detail with side exposed

2.2. Measurement Procedure

Reverberation times (RT) were measured before and after installation according to ISO 3382-2 for ordinary rooms.

Measurements were carried out on:

- 30 May 2025 (before installation)
- 8 July 2025 (after installation)

Results were corrected for the change in conditions (humidity) according to ISO 354, see Table 1. Reverberation time was evaluated using the average of T_{20} and T_{30}, excluding data below 100 Hz due to background noise.

Table 1: Measuring conditions

Condition	**Empty Room** Ground floor / 1st floor	**With Panels** Ground floor / 1st floor
Temperature [°C]	23.4 / 24.6	26.6 / 28.1
Humidity [%]	43 / 44	49 / 45
Barometric Pressure [hPa]	995	978

2.3. Results

2.3.1. Reverberation Times

After installing the Hempstatic panels, the reverberation time in both rooms decreased significantly, see Figure 2, Figure 3. At 500 Hz, a representative mid-frequency band, the reverberation time in both rooms was reduced by approximately 0.5 seconds compared to the empty state. This indicates a significant improvement in sound absorption, which meets and even slightly exceeds the laboratory's expectations.

The results show that the panels effectively reduced reverberation in the mid and high frequency ranges, improving speech intelligibility and overall acoustic comfort in the room.

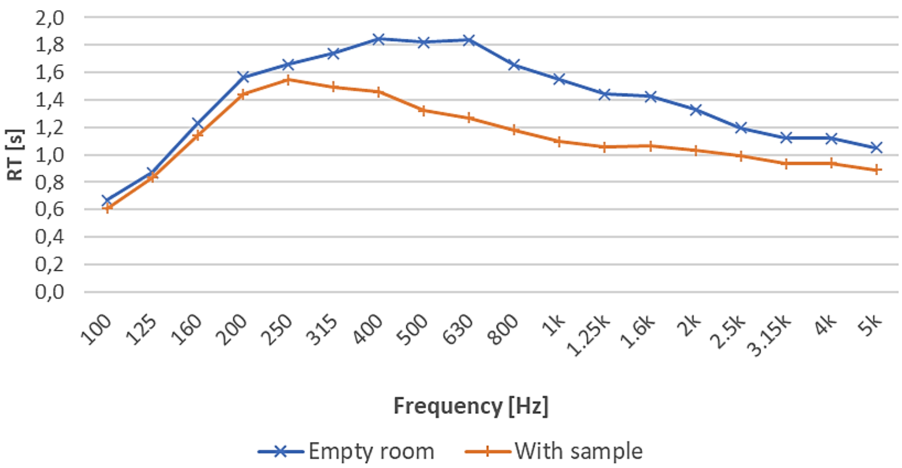

Figure 2: Change of reverberation times in 1/3rd octave bands, with and without panels (1st floor).

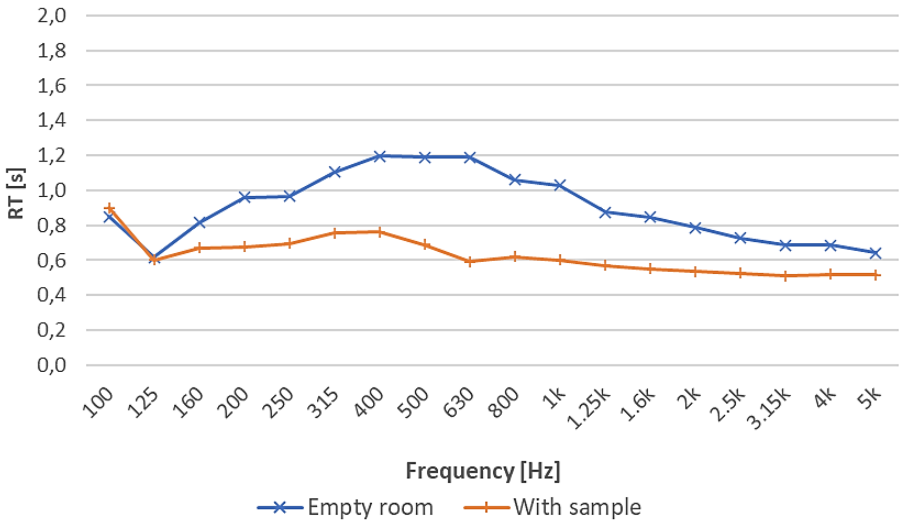

Figure 3: Change of reverberation times in 1/3rd octave bands, with and without panels (ground floor).

2.3.2. Optimum Reverberation Comparison

For rooms of this size (about 150–180 m³), the optimum RT for speech is approximately 0.9 s ± 20 %.

After installation,

- the value in the ground floor room was slightly below the optimum,
- while the value in the first floor room remained slightly above the optimum.

This difference is due to the greater distance and lateral orientation of the panels on the ground floor, which improved absorption.

2.3.3. Apparent Sound Absorption Coefficient

The apparent sound absorption coefficients (α_s) were calculated in accordance with ISO 354 based on the change in reverberation time. Although the arrangement does not meet all standard requirements, the results provide valuable indicative data.

The panels on the ground floor with a larger exposed surface area achieved the highest apparent absorption coefficients, followed by the installation on the first floor, both exceeding the laboratory reference curve. These results underscore the importance of installation geometry and exposed surface area for effective acoustic performance in situ.

2.4. Conclusion and Discussion

Laboratory and pilot tests with Hempstatic panels confirm their suitability as a low-emission, recyclable acoustic solution for sustainable interior design. Laboratory tests in accordance with ISO 354 revealed high and broadband sound absorption with coefficients rising from ~0.6 at 500 Hz to > 0.9 at 1 kHz.

On-site pilot measurements confirmed these results under real conditions and even showed an even higher apparent absorption. Both data sets showed consistent behaviour and confirmed the reliability of the laboratory predictions for practical applications.

Overall, the panels offer:

- effective absorption of medium and high frequencies,
- improved acoustic comfort,
- low environmental impact,
- and complete recyclability within a circular design concept.

However, performance is sensitive to the installation configuration, particularly lateral exposure and the distance between panels. Future work should therefore focus on optimising panel placement, evaluating long-term durability and assessing thermal insulation performance.

The results of further on-site monitoring and user feedback will be included in the final pilot project documentation under Deliverable A.2.5.

3. Recycled Concrete with 100 % Recycled Aggregate (PP14)

Consistent with the principles of the circular economy and resource conservation, **recycled concrete with 100 % recycled aggregates** was developed at HM (PP14).

The recycled aggregate came from the demolition site “Bayernkaserne München” supplied by the project partner “Ettengruber”. The concrete was first developed and tested in the laboratory to assess its mechanical and durability properties and was later applied in the “Campus Ost” pilot project in Munich, in cooperation with the City of Munich. In the project a special permission by the building ministry of Bavaria was necessary, because recycling concrete including 100% recycled aggregate is not according to german standards.

3.1. Concrete Mixture

Based on the test mixtures from Deliverable D.2.2.2, test specimens were produced at the Bayernkaserne mixing plant.

Table 2 presents the final mixture composition used for all testings.

Table 2: Mixture composition of 100 % recycled concrete

Type	Density [kg/m³]	Mass [kg/m³]	Volume [dm³]
Variocem W5	3.05	506	166
Water	1.00	169	169
Suction Water	1.00	100	-
Plasticiser + Synthetic resin (50/50)	-	7	-
RCA (AB16)	2.50	1587	635
Air	-	-	30
Σ	-	2269	1000

3.2. Pumping Test

A full-scale pumping test (see Figure 4) was conducted using a 40-metre concrete pump provided by the company “Zehentner Pumpendienst”.

The concrete maintained a consistent, workable texture after pumping, confirming its suitability for in-situ construction. Test specimens were cast from the concrete immediately after pumping.

Figure 4: Pumping test on the Bayernkaserne site with 100 % recycled concrete

3.3. Fresh Concrete Properties

1 m^3 of concrete was mixed in a large-scale mixer.

Slump tests according to DIN EN 12350-5 were performed at 10, 30, 60, and 90 minutes after mixing. The spread decreased from 55 cm to 31 cm within 90 minutes (F4 → F1 consistency). A slump reduction of about 14 cm after 60 minutes indicates moderate workability loss over time.

Fresh density and air content were determined according to DIN EN 12350-6 and DIN EN 12350-7. The fresh density was about 2299 kg/m^3, and the air content was about 2.2 %. Both values deviated only slightly from the expected range.

3.4. Hardened Concrete Properties

3.4.1. Mechanical Properties

Compressive strength was determined after 2, 14, 28 and 56 days in accordance with DIN EN 12390-3. The Young's modulus was measured after 28 and 56 days according to DIN EN 12390-13. Results are presented in Table 3.

Table 3: Results of the hardened concrete tests

Age [d]	Compressive Strength (Cube) [N/mm²]	Young's Modulus [N/mm²]
2	25.1	-
14	42.0	-
28	55.8	26300
56	60.4	27233

After 28 days, compressive strength class C35/45 (target strength C30/37) was achieved. Compared to EC2 estimations (Young's modulus ~33,000 N/mm² for C30/37), the measured modulus values were significantly lower.

3.4.2. Bond Behaviour

Bond strength between reinforcing steel and concrete was tested according to RILEM RC6 / DIN EN 10080 using five specimens with 10 mm B500B rebar and 50 mm bond length.

Average bond stress-slip curves (see Figure 5) confirmed stable bond performance and adequate post-cracking behaviour comparable to conventional concrete.

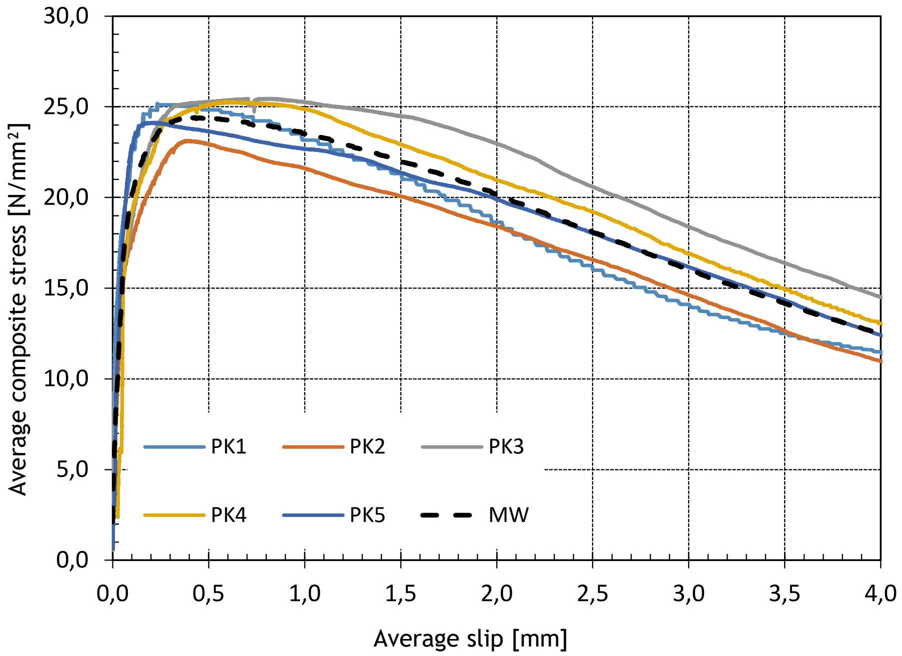

Figure 5: Bond stress-slip curves (individual curves and mean curves)

3.4.3. Deformation

Drying shrinkage was measured over 140 days (DIN EN 12390-16), showing a total shrinkage of 0.65 mm/m (0.065 %), about 45 % above the EC2 estimate for C30/37 (0.045 %). Creep tests (DIN EN 12390-17) showed a creep coefficient of 1.22 after 35 days, which was approx. 17 % above the EC2 reference values.

Overall, the deformation behaviour remained within the typical range for recycled concrete.

3.5. Durability Properties

3.5.1. Freeze-Thaw Resistance

Frost-thaw resistance was tested in accordance with CEN TR 15177. After 56 cycles, surface spalling amounted to 122 g/m², which was significantly below the limit value of 1000 g/m².

The concrete therefore meets the requirements of stress class XC3.

3.5.2. Carbonation Resistance

The carbonation depth was measured under accelerated conditions (3 Vol.-% CO_2, 65 % RH, 20°C) in accordance with DIN EN 12390-12.

The results show moderate carbonation progress with a calculated service life index β > 1.5 after 45 years for exposure class XC4, confirming sufficient long-term durability.

3.6. Implementation in a building

In the building site “Campus Ost we achieved a special permission to use recycling concrete containing 100% recycled aggregate. A few elements were produced with recycling concrete, which contains 100% recycled aggregate: The bore piles (see Figure 6), parts of the foundation (see Figure 7), walls in the basement (see Figure 8)and one ceiling panel in the second floor (see Figure 9).

Figure 6: Left: Prepared building site with the drilling template produced with recycling concrete with 100% recycled aggregate; middle: fresh concrete during producing a bore pile with concrete with 100% recycled aggregate; right: hardened borepiles

Figure 7: Foundation made of recycling concrete with 100% recycled aggregate

Figure 8: View on the ceiling panel from below made of recycling concrete with 100% recycled aggregate

Figure 9: walls in the basement made of recycling concrete with 100% recycled aggregate

3.7. Conclusion and Discussion

As part of the 'Campus East' pilot project, a 100% recycled concrete was successfully developed and tested for use in building components. The mixture achieved the required strength class C30/37 (≈ C40/50 after 56 days) and demonstrated good workability and pumpability, thus fulfilling the practical requirements of the construction industry.

Extensive testing confirmed that the concrete has reliable mechanical strength, stable bonding behaviour, sufficient durability and acceptable deformation properties. The compressive strengths achieved of ≈ 56 N/mm^2 (28 d) and ≈ 60 N/mm^2 (56 d) and a modulus of elasticity of ≈ 26–27 GPa indicate consistent performance.

Overall, the results show that 100% recycled aggregate concrete can meet structural and durability requirements comparable to those of conventional concrete when designed and manufactured correctly. This material represents a practical, resource-efficient and climate-friendly alternative that supports the transition to circular construction.

Further in-situ tests on the performance of recycled concrete are currently being carried out as part of the Campus East pilot application. The results and long-term monitoring data will be evaluated in Activity A.2.5, Final Report of the Pilot Project.

4. Conclusion

The implementation of new circular products as part of the ReBuilt project has demonstrated that sustainable material innovations can be successfully adapted from laboratory development to real building applications.

Both pilot projects confirm the technical feasibility, functional performance and environmental benefits of the tested products:

- Hempstatic hempcrete panels proved to be an effective, low-emission and recyclable acoustic solution. On-site tests in Slovenia confirmed a significant reduction in reverberation times and validated the acoustic efficiency of the panels under real building conditions.
- The concrete developed and used in Germany, made from 100% recycled aggregate, achieved the required strength, durability and workability for use in structural components, confirming its suitability for circular construction methods.

The successful integration of these materials highlights the potential of circular products to reduce CO_2 emissions, save resources and replace conventional, non-recyclable materials. Their use in pilot applications demonstrates their technical feasibility.

Ongoing in-situ monitoring will provide additional insights into long-term performance. These results will be published in Deliverable A.2.5, Final Report on the Pilot Projects.