

## Artistic Shotcrete for a Historic Auditorium

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**T**he Goetheanum (Fig. 1) in Dornach, near Basel, Switzerland, was constructed in the late 1920s from a design by Austrian social philosopher and “spiritual scientist” Rudolf Steiner. This building represents the first use of reinforced concrete for monumental, sculptured forms.

In terms of the history of architecture, it is difficult to assign any particular style to the structure. In fact, it was one of many endeavors undertaken at the beginning of the 20th century that was motivated by the desire to explore entirely new avenues of thought and style. Steiner wanted to create an appropriate outer envelope for the activities of the spiritually striving movement it would house. Thinking of the way a nut is encased in its shell, he sought to create a comprehensive work of art in which architecture, sculpture, painting, music, speech, theatre, eurythmy, and elocution should all spring from one and the same fundamental idea.

The building constitutes the worldwide center of the Anthroposophical Society. It contains a stage for the movement’s acting and eurythmy companies, headquarters of the School of Spiritual Science, and rooms for the 130 to 150 conferences and meetings held at Dornach each year.

The Anthroposophical Science of the Spirit was founded by Steiner at the beginning of the century, with the aim of attuning human spirituality and, at the same time, developing new ideas for many areas of practical endeavor. Results of

the movement include the Rudolf Steiner Schools, anthroposophical medicine with its many clinics and private practices, biodynamic agriculture, art schools, etc.

### Building history

The first Goetheanum was a wooden structure erected between 1913 and 1920 where the present one stands. Its interior, in particular, was lavishly decorated with sculptures and murals. Then, in 1922, the building was burned to the ground by an arsonist. Today’s Goetheanum was begun in 1925, and its concrete shell was completed in 1928. The interior of the main auditorium, finished in 1957 in a rather rudimentary fashion, included a suspended ceiling coated with asbestos.

In 1989, when the removal of this asbestos ceiling was mandated by environmental concerns, work began in earnest on the artistic aspects of refurbishing the auditorium. Various architectonic, acoustic, and technical alternatives were considered, starting in 1993. Besides removal of the asbestos ceiling, it was necessary to renew and improve the heating, ventilation, and cooling systems; the lighting; and, above all, the acoustics, which had always been unsatisfactory.

The main problem from the acoustical standpoint was presented by the sheer size of the room — 17,000 m<sup>3</sup> (22,200 yd<sup>3</sup>) — which had formerly contained seating for more than 1000. The philosophical underpinnings of the work to which the Goetheanum was devoted precluded the use of any type of loudspeaker system.

The artistic aspect of the new interior was the subject of great anticipation. How could one possibly create a new, modern interior within the constrictions of a structure conceived in 1925? Ultimately, the model conceived by Christian Hitsch, head of the Goetheanum’s Art Section and bearer of artistic responsibility for this project, crystallized by the time work was to begin. Based essentially on the structural interior of the original Goetheanum, it features majestic, free-standing columns topped by sculptured capitals and



Figure 1: The Goetheanum in Dornach.

sweeping architraves, and finally, by the broad ceiling with its painted motifs.

Initially, a key question to be decided concerned the type of material to be used for the renovation. Following tests with wood — including a carved sample measuring 4 x 7 m (13 x 23 ft) scale 1:1 — and an extended period of research with concrete, it was decided to produce shells of shotcrete.

## Shotcrete elements in the main auditorium

Shotcrete is generally applicable for thin structural elements covering large areas and for ones with complex shapes. It is considered wherever conventional concrete is difficult to place, requires expensive formwork, or both. These conditions exactly describe the interior elements of the Goetheanum's main auditorium. They are indeed very thin shells comprised of multiple contours and finely textured surfaces, which could not possibly be produced with cast-in-place concrete at an acceptable price. Finally, the fundamental decision to use mineral aggregates settled the matter: shotcrete was the only feasible solution.

An initial trial with the dry-mix shotcrete process produced intolerable clouds of dust because of faulty procedures, so trials were undertaken with the wet-mix process. These failed because the equipment available was not suitable for this particular purpose. When it was found that the dry-mix shotcrete, correctly applied, actually produced relatively little dust, this process was ultimately adopted. Next, it was necessary to find solutions to the problems created by the extremely unusual shotcrete application in the Goetheanum:

- Because the elements had to be created from a void, so to speak, a substrate was needed against which to apply the shotcrete;
- In view of the auditorium floor's limited load-bearing capacity, the elements needed to be as light—that is, as thin—as possible;
- After application, the shotcrete layer was to be sculpted with hatchets, so the material had to be capable of withstanding this treatment;
- Very precise ideas existed about the final appearance of the sculpted shotcrete, so the basic mixture had to be produced accordingly;
- Since the required dry mixture was not available commercially as a factory premixture, it had to be mixed on the job site;
- The conditions at the site made it necessary to set up the mixing equipment and the shotcrete gun outdoors next to the building. The mixture had to be conveyable over a horizontal distance

of 120 m (400 ft) and about 30 m (100 ft) vertically to reach the nozzle; and

- Shotcreting had to be done efficiently and safely at a reasonable cost.

It took many meetings and more testing to find workable answers to all of these questions. Fortunately, the shotcrete contractor, Laich SA, had gained very valuable experience doing surprisingly similar work to produce artificial rocks in the Zurich Zoo's new bear enclosure from 1994 to 1995.

The interior elements of the auditorium are supported by a structural frame of steel columns and girders that stands on the auditorium floor and is anchored to the walls. Fastened to the frame is a network of shaped reinforcing rods and wires, the "skeleton of round steel." These basket-like relief sculptures were made by artisans, some as prefabrications and others on the spot.

The "skeletons" of the entire capital and architrave portion of both side walls and the column bases were fabricated on the shop floor of a metalworking plant. This was done by plotting 1200 measurement points in three coordinates on the sculpted model of each side wall and then reproducing them on the shop floor. These prefabricated skeleton sections were transported to the job site, where they were fitted together. The remaining skeleton parts — for the columns, side walls, and front and back walls — were assembled on the spot.

To provide the actual substrate for the shotcrete, "lost formwork" was fastened behind the skeleton. It consisted of expanded metal made of 0.5 mm (20 mils) gage iron sheet. This material is easy to cut and shape, permeable to air, and sufficiently stiff. It was fastened with tie wires and plastic spacers 20 mm (3/4 in.) behind the bars and wires of the skeleton (Fig. 2). This distance was essential to make sure that the skeleton would be solidly embedded in a shotcrete layer roughly 100 mm (4 in.) thick. The cutting, fitting, and fastening of this formwork was a very tedious job, especially in the areas with complicated shapes.

The following dry-mix shotcrete composition satisfied all the requirements established for the mixture and the hardened shotcrete in the Goetheanum:

- pumice aggregate, particle size 0 to 8 mm (3/10 in.);
- expanded clay, 0 to 3 mm (1/10 in.);
- white marble sand;
- nine parts white cement;
- one part hydraulic lime; and
- red mineral colorant (iron oxide).

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Figure 2: Skeleton with expanded metal fastened behind as “lost formwork.”



Figure 3: Shotcreting on this project required painstaking care.

This mixture was produced on the job site with a pan mixer in batches of about 125 L (30 gal.). It lent itself well to conveying and yielded fresh shotcrete that was plastic and adhered well (Fig. 3). As a result, even the backs of the skeleton rods were fully covered. Fortunately, too, the filling out of corners and acute angles proved much less difficult than had been feared. It was possible to achieve the desired shotcrete thickness in just one operation. In addition, the relatively rough shotcrete surface provided effective “interlocking” of the successive shotcrete layers.

The shotcrete shell was applied in a layer about 100 mm (4 in.) thick. For efficient distribution of

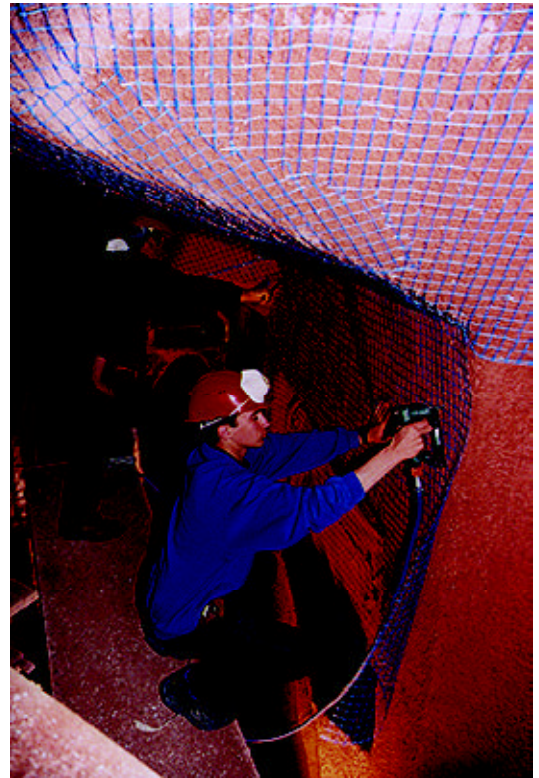


Figure 4: Application of the glass fiber mesh.

shrinkage strains, it was reinforced with a glass fiber mesh (Fig. 4). The blue mesh was covered with about 40 mm (1.5 in.) of shotcrete. It served as a useful indicator later in the texturing process to warn craftsmen against removing too much material (Fig. 5).

The tests carried out for quality assurance verified the following shotcrete properties after 28 days:

- Dry density ( $n = 3$ ): 1183 kg/m<sup>3</sup> (1995 lb/yd<sup>3</sup>);
- Total porosity ( $n = 2$ ): 47.2 % by volume;
- Compressive strength ( $n = 6$ ): 23.8 MPa (3450 psi);
- Tensile strength, axial ( $n = 9$ ): 1.0 MPa (145 psi); and
- E-modulus ( $n = 3$ ): 9.13 GPa (1320 ksi) ( $n =$  number of tests).

A total of 705 m<sup>3</sup> (922 yd<sup>3</sup>) of dry-mix was produced for the shotcrete. The developed surface of the sculpted shotcrete totaled about 2170 m<sup>2</sup> (23,400 ft<sup>2</sup>).

The renovation of the main auditorium (Fig. 6 and 7) was completed in a surprisingly short time. Only 19-1/2 months passed between the final curtain prior to the start of work and the inaugural performance in the renovated auditorium. In this period, exactly 200 workdays were needed to produce the shotcrete elements, including installation of the round steel skeleton,

# Shotcrete Classics



Figure 5: Sculpting of the shotcrete.

fastening of the lost formwork, shotcreting, and sculpting of the surface after the shotcrete had set. In all, 4270 manhours were expended for the actual gunning of the shotcrete.

An average of 35 artisans from all over the world worked just over six months to sculpt the hardened surface, using hatchets to finish the carving and produce the textured surface. The result is a unique combination of architecture and sculpture. Despite the excellent composition of the dry-mix, it took highly experienced and skilled nozzle men exercising painstaking care to achieve the desired results. In the end, these requirements were met and the final shotcrete surface earned the acclaim of the artists and sculptors working on the renovation.

The texture and appearance of the sculpted surface (Fig. 8) are remarkably uniform. No serious color fluctuations or structural faults are in evidence. The extent of defects sometimes found in shotcrete work, such as rebound inclusions, poor bonding between layers, and “shadows” behind reinforcing rods, is negligible. Most amazing of all is the fact that only very few cracks have yet been found in the complex structures.

These gratifying results are attributable partly to good engineering practice and partly to the skill, diligence, and conscientiousness of everyone involved. Part of the results had to do with an exceptionally pleasant atmosphere on the job



Figure 6: Partial view of an auditorium wall with columns, capitals, and architrave.

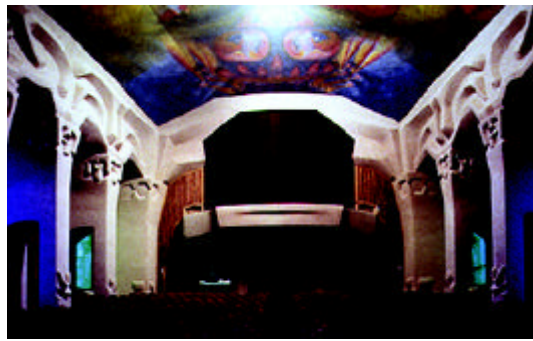


Figure 7: The totally refurbished main auditorium of the Goetheanum.

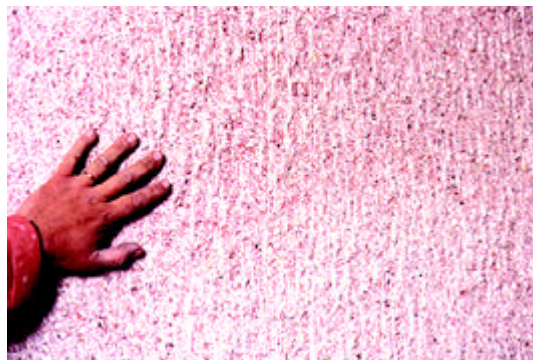


Figure 8: Shotcrete surface after hatchet treatment.

site, the mutual friendliness of all hands, and the obvious desire of everyone to get along with one another. It must be admitted, too, that the whole crew — shotcrete applicators, sculptors and volunteer helpers — had more than a little bit of luck, especially considering the complexity of the project and all the things that might have gone wrong.

Photo credits: Fig. 1 — Goetheanum, Dornach; Fig. 6 and 7 — Jurg Buess, Basel; Fig. 2, 3, 4, 5, and 8 — Laich SA, Avegno.

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