Editorial

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Reinforced concrete is not a durable material. Chemically considered, its lifetime is intrinsically limited. Although the concrete itself can suffer from irreversible and incurable deterioration, such as the alkali–silica reaction, by far the most common problems of aging encountered with reinforced-concrete structures arise from faulty workmanship and/or insufficient protection of the reinforcement. Fortunately, these issues can usually be addressed. With surfaces exposed to air, carbonation of concrete will inevitably take its toll on the alkalinity of concrete covers and put the steel reinforcing bars at risk of expansive corrosion inducing the spalling of concrete. Nowadays, with theoretical models and when all parameters (concrete composition, geometry and environmental conditions) are known, it is theoretically possible to predict when the carbonation or other ingressive fronts will reach the reinforcing bars. In practice, especially for structures built before the enforcement of durability considerations in standards and codes of practice, such parameters are not mastered. We may observe reinforced-concrete structures built more than a century ago that are still in fairly good condition, whereas others built in the 1970s and exposed to harsh service conditions have to be scrapped.

Some reinforced-concrete structures are considered as icons in the standard literature for engineers or architects because, in their respective fields, they represent milestones in the development of the art of designing, creating or constructing. These structures may or may not be listed. Most bridges that structural engineers would designate as ‘iconic’ are probably not heritage listed. Although reinforced-concrete structures are not durable, extending their life by remedial measures can make a significant – though often overlooked – contribution to sustainable construction. If an age-deteriorated construction may still prove useful after renovation, why not invest in its rehabilitation with a sustainable construction-minded approach instead of building a new concrete structure with new CO₂ costs? The question is particularly interesting for those iconic and heritage-listed structures which still impress with their gigantic proportions, but which were built for a particular function that is now obsolete and, hence, are difficult to reuse. This is the case, for example, with old aircraft hangars and industrial halls. Moreover, when such constructions are renovated to extend their useful life, the repair strategies generally result from discussions with a wide range of parties including conservation agencies. Considering their particular value, the best available renovation practices are selected and the interventions are kept under evaluation. Sometimes highly innovative materials or repair strategies are introduced, justified by the iconic character of the structure to be saved. It is therefore of the utmost importance to record, in scientific papers, recent experiences of renovating, repairing and refurbishing such iconic concrete structures. These projects are true laboratories for testing rehabilitation strategies *in situ* and at full scale.

The call for papers for this issue focused on buildings and structures of architectural interest excluding bridges, which often suffer – especially road bridges – from specific deterioration problems. We had in mind the recent rehabilitation of such iconic concrete structures as the following

- The huge ribbed dome of the Centennial Hall in Wrocław (Poland), formerly Breslau (Germany), completed by Dyckerhoff & Widmann in 1913. At that time it was probably the largest column-free enclosed space (dome diameter 65 m) covered by a roof in reinforced concrete (Huber *et al.*, 2010; Onysyk *et al.*, 2014).
- The Market Hall in Frankfurt (Germany), completed in 1928, was the first significant application of the Zeiss-Dywidag (Z-D) patent for building long, thin-shell, cylindrical barrel vaults with 36 m spans, designed by Franz Dischinger and Ulrich Finsterwalder from Dyckerhoff & Widmann (Hankers *et al.*, 2012).
- The Market Hall in Reims (France), completed in 1929, was the French counterpart of the Frankfurt Market Hall, where Eugène Freyssinet designed short, thin-shell, cylindrical barrel vaults with the same free span (36 m) (Charlot and Truillet, 2012).
- The Market Hall in Leipzig (Germany), also completed in 1929, designed by Franz Dischinger, had hexagonal domes made from thin Z-D shell segments covering a free surface. While similar in size to the Centennial Hall, the weight of concrete was reduced to a third of Wrocław dome (Lorenz *et al.*, 2013);
- The canopy of the grandstand of the Zarzuela racecourse near Madrid (Spain), one of the thin-shell masterpieces of Eduardo Torroja, begun in 1934 and inaugurated in 1941 (Castillo *et al.*, 2011).

This issue presents a balanced selection of four case-study papers dealing with the refurbishment of masterpiece concrete structures from different periods (1917–1975), and different places in the UK and continental Europe. They also introduce various building types, expanding the importance of the topic of precise concrete rehabilitation beyond the icons of interwar concrete engineering.

Mändel and Öiger (Mändel and Öiger, 2016) recall the story of an extraordinary seaplane hangar built in Estonia by the Danish contractor Christiani and Nielsen in 1916–1917. It belongs to the very early history of thin, concrete-shell structures and therefore presents an important complement to the above list of refurbished thin shells. It consists of three side-by-side cupolas. Thin concrete-shell cupolas had been designed and constructed before 1916, but certainly not with such large dimensions. This structure is a remarkable testimony of the early use of concrete for aircraft hangars. Another surviving hangar from about the same period is the last of a series of eight

short, barrel vaults (span 46 m) by Eugène Freyssinet, built at Avord near Bourges (France) in 1915–1916 (Labbeuw, 2013). The authors describe the very poor condition of the roof, which was fully carbonated across its depth (from 8 cm to 15 cm), before the renovation works began, and details the interventions undertaken to allow this spectacular structure, which surprisingly survived throughout the 20th century, to become host to a maritime museum.

Tappin (2016) gives a clear and detailed report on the process of renovating the reinforced-concrete constructions of Dudley Zoo, one of the most important ensembles that promoted modern architecture in the UK. It consists of 12 buildings constructed in 1937 by Berthold Lubetkin and Tecton Architects, with Ove Arup as consulting engineer. The main problem encountered was degradation due to the insufficient thickness of the concrete cover to the reinforcement found in most concrete elements, rather than the depth of carbonation, which was about 4 cm. Concrete or mortars made with traditional materials were preferred for repairing the damaged surfaces. In some places, it was necessary to apply carbon fibre strips to increase the capacity in bending and shear. The methods used to refurbish these small buildings and constructions are exemplary of contemporary practices advocated by conservationists when dealing with heritage concrete structures.

Iori and Poretti (2016) unveil some of the mysteries surrounding the origins and first applications of ferrocement, a composite material with high performance, patented and developed by Pier Luigi Nervi from 1943 onwards. Their paper highlights the restoration of two very different structures, both having very thin wall thicknesses that characterise ferrocement structures. While the thickness of only 10 mm or so was a key advantage and reason for using this composite material, it was also the weak point in the durability of the system. For most non-Nervi-specialists, the familiar application of ferrocement is probably the construction of economical ship hulls in the post-war years. Most of these hulls have now disappeared, but the last, the prototype fishing boat *La Giuseppa* built in 1972, has recently been restored for permanent exhibition at the University of Tor Vergata in Rome, Italy. This boat will remind us of the rowing boat made by Joseph-Louis Lambot which, according to some (usually French) historical accounts, is the *incunabulum* of reinforced concrete in 1849. In fact, constructing vessels in reinforced concrete occurred at other times of scarcity of metals; for example, during and just after the First World War. The second structure discussed in the paper is a warehouse built by Nervi in the Magliana district of Rome in 1945, whose walls and corrugated roof are entirely of thin ferrocement, and will probably be new to most readers. Being a prototype, it testifies to the early experiments by Nervi with his new material. It may also be the oldest one and therefore an interesting case study for developing specific restoration strategies for this material and system.

In the final paper, Douglas (2016) discusses the renovation of some concrete parts of the National Theatre in London, an icon of English brutalist architecture by Denys Lasdun dating from the early 1970s. At first glance the conservation problems here seem minor in

comparison with the problems suffered by the older constructions analysed above, since the workmanship and concrete quality at the National Theatre were of much higher quality by that time. Nevertheless, in some places it was necessary to stop degradation, especially where previous repairs undertaken in the 1990s had not performed as expected. The specific challenge in the restoration was to preserve the board-marked finish. As with the repair works at Dudley Zoo, the strategy recommended by the conservation agency was to use concrete and mortars with traditional materials as much as possible, avoiding the use of polymer modified mortars. In this case, it was even possible to prepare concrete mixes using aggregates from the same provenance as the original concrete, which helped with matching the original colour and texture.

The editor thanks all authors for sharing their experience in renovating concrete iconic structures.

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