The Stavros Niarchos Foundation Cultural Center (SNFCC) in Athens’ southern district of Kallithea, which translates as ‘beautiful view’. Kallithea was once a major port for Athens, but rapid urban development in the 20th century detached the site from the water. The project’s architect Renzo Piano resolved to restore this connection visually if not physically. He conceived the idea of an artificial hill on which a sloping park, prevented from physically turning the building inside out and introduced the public to exposed services and structure. With the SNFCC, he wanted the opposite: a simple canopy, with no overt details of struts, cables or associated services.

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HISTORY OF FERROCEMENT

Ferrocement was invented by French gardener Joseph-Louis Lambot in the 1840s. He found that by embedding fine meshes of iron wire in a thin layer of hydraulic cement/sand mortar, he could produce a material that was light, strong, cheap, water resistant and easy to form in irregular shapes. He recommended his ‘fercement’ as a replacement for wood anywhere that water resistance was important, such as floors, water tanks and planters, and he used it to build a rowing boat. His invention pre-dated reinforced concrete. However, producing the wire mesh at that time was labour intensive, and the production of larger diameter bars, and later the introduction of steel bars, led to ferrocement being overtaken by reinforced concrete and largely forgotten for a century.

The idea was picked up by Italian structural engineer Pier Luigi Nervi who was commissioned during the Second World War to design ferrocement boats. In 1945, he built one of his own – a 165-foot-long yacht with a hull 35 millimetres thick. He included ferrocement elements in his subsequent buildings, such as his celebrated 94-metre-span Hall 8 for the Turin Exhibition in 1948-49, and later used the material as permanent formwork for buildings including those for the 1960 Rome Olympics.

Since then, ferrocement has had a niche following among engineers who appreciate its fine qualities: potentially cheap and simple to make with no formwork required (although formwork was used in Athens), surprisingly elastic, resistant to cracking because of the close spacing of the steel wires (and hence durable when wet), and easily formed into complex shapes. Applications have included: specialist roofs, notably in the Middle East; water tanks in India; low-cost housing in the developing world; large-scale sculptures; ‘concrete canoes’ built and raced by engineering students; and research were limited, there was no appropriate codes for the cantilever structure needed within the opera house by as much as 40%, therefore reducing the structure needed within the opera house to transfer the load to the foundations. It also optimizes the dynamic performance of the canopy under wind or seismic loading, and increases the predictability of the internal forces for which the ferrocement is designed.

Conventional structural analysis software is not well set up for understanding and developing such mechanical systems, so physical modelling was central to the design process. This began with modelling in Meccano, followed by bespoke numerical kinematics modelling, 3D printing with mechanical springs, developing a full design in 3D (building information modelling), and finally building and testing the column head system at full-scale. Each column head includes a stiff steel frame fixed to the ferrocement, four springs providing for movement up to +/-130 millimetres, dampers to dissipate energy from wind and seismic movement, and low-friction bearings for robustly and rigidly carrying large lateral loads. At the suggestion of the contractor’s engineers, fluid polymer springs were chosen, adapted from the buffers of French TGV (high speed) trains. This had the added advantage, that on the completion of construction, the act of pumping the fluid polymer into the springs allowed the canopy to ‘float’ over the opera house, and create very high local stresses, which can develop a full design in BIM (building information modelling), so in order to give contractors the opportunity to ‘float’ over the opera house by as much as 40%, therefore reducing the structure needed within the opera house to transfer the load to the foundations. It also optimizes the dynamic performance of the canopy under wind or seismic loading, and increases the predictability of the internal forces for which the ferrocement is designed.

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The final result is a 100 metre by 100 metre PV array made up of 5,560 panels delivering 1.3 MW (megawatt) of power, and expected to generate 2 GWh (gigawatt hours) per year, similar to powering 650 UK family homes. Additional power will be required from the grid at peak times, but at other times the PVs will feed surplus power into the grid.

The key to seismic protection for the building is the network of 320 pendulum base isolators underneath it, which reduce lateral seismic loads by 80%. Underlying soils are a mix of liquefiable sands and clays that can be softened. The building was effectively isolated from these by piles down to bedrock, but the artificial hill had to be protected with reinforced earth-retaining walls and localised stone columns sunk into the existing ground. A ‘buffer zone’ isolates the building from the hill.

The buildings themselves are much more conventional in design than the canopy, mainly using reinforced concrete, Greece’s most common building material. As part of the sustainability strategy, the buildings are, where possible, ‘layered’ like onion skins, with the most sensitive, carefully controlled environments (such as the rooms containing precious manuscripts) at the centre and rooms with greater tolerance to variations in temperature and humidity on the outside. Shade reduces solar gain, in particular the canopy over the opera house and carefully designed, retractable roller blinds on the glazed façades. The sloping park, which rises over the top of the library in the form of a grass roof, improves thermal insulation.

Good insulation, low-energy lighting and extensive use of a highly efficient displacement ventilation system help to keep energy demand down. Air is handled using centralised air conditioning systems.
conditioning is still required, but its efficiency is increased by the use of heat recovery chillers. These recycle the heat rejected by the air conditioning to pre-heat domestic hot water from 20°C to 47°C, leaving conventional gas-fired heaters to do the rest.

All of the plant had to be hidden, with only limited space. Grey-water (all waste except from toilets) collection tanks are in the undercroft, and the large air intakes are through gratings in the park floor in the ‘buffer zone’ where the park joins the library roof. The chillers are discreetly located by the car park. In the vicinity of the opera house auditorium, the plant also had to be silent, leading to large low-ventilation ducts requiring relatively little fan power.

The net effect of all these measures is an estimated reduction in annual energy consumption of more than 40%, compared with a ‘standard’ building with an identical geometry and in the same location. The 1,400-seat auditorium had a successful ‘test run’ in November 2016 when it hosted a speech by then President of the United States, Barack Obama, and the centre is due to be commissioned in stages over the early months of 2017, after which it will be handed over to the Greek State.

WATER SELF-SUFFICIENCY

Athens’ climate combines hot, dry summers with flood-risk storms, which created challenges for irrigating the 15-hectare sloping park without drawing on scarce potable water supplies. It led to the development of innovative water and drainage solutions including SUDS (sustainable urban drainage system) and rainwater harvesting.

The first measure to conserve water was the choice of plants for the park: native Greek species and other Mediterranean plants that are relatively tolerant of dry conditions and require minimal irrigation. The principal water source is brackish groundwater from four boreholes on the edge of the park, which has to pass through a desalination plant before use. This is supplemented by seawater drawn from the bay and pumped across a bridge over the ring road to the site for desalination. The seawater is also used to refresh the ‘canal’ that runs along one side of the site.

All of the rainwater falling on the canopy over the opera house is caught in an invisible gutter along the perimeter, channelled within the canopy, dropped down pipes inside the steel columns supporting the canopy, and carried to buried gravel trenches located throughout the park that infiltrate the rainwater and allow it to recharge the aquifer below the park.

Stormwater in the park, particularly from the hard surfaces of the paths, is collected in drainage channels and carried to the gravel trenches and a set of buried, geotextile attenuation tanks. These serve two purposes: they absorb much of the water from a peak storm, so prevent overload on the local stormwater drainage system; and they allow the stormwater run-off to percolate through the ground and also recharge the aquifer. This is designed to cope with anything up to a 1-in-50-year storm. For anything greater and up to a 1-in-200-year storm, part of the park would be allowed to flood. Water from the seawater canal would rise to inundate the surrounding paths, but not the cultural centre itself.

Within the buildings, water demand is reduced by measures such as low-flow appliances and fixtures and waterless urinals. Grey water (all waste except from toilets) from the opera house is collected, filtered, and where necessary treated, stored and then recycled for uses such as toilet flushing.

Altogether these measures reduce the development’s impact on the local water utility infrastructure by 37,000 cubic metres, equivalent to 15 Olympic swimming pools per year.

Onsite surface water attenuation is provided throughout the park in the form of geocellular tanks and deep gravel trenches. Both act to store water during times of heavy rainfall, which protects the municipal drainage system from being overloaded and allows for infiltration to recharge the aquifer © Michel Denancé

BIOGRAPHY

Bruce Martin is an Associate Director at Expedition Engineering. He led the structural engineering design of the SNFCC. Bruce has a keen interest in elegant, innovative and practical engineering solutions that provide a clear benefit to the client.

Darren Barlow was the Project Director for the SNFCC project. He has over 25 years of experience in engineering design, encompassing an extensive range of general building services, environmental passive design techniques, and the application of renewable and low-energy technologies.

David McAllister was the Project Manager at Arup, leading the SNFCC project from concept through to construction. As the lead MEP (mechanical, electrical, plumbing) engineer, David guided coordination between disciplines and steered the sustainability strategy.