Learning legacy
Lessons learned from the London 2012 Games construction project

Sustainability of the Aquatics Centre

Abstract
‘Legacy’ is the concept that underlies the sustainability agenda of the London 2012 Olympic and Paralympic Games, embracing temporary infrastructure and venues to leave behind a vibrant, productive community with world-class, affordable sporting facilities.

The Aquatics Centre, developed as an architectural icon, was the most complex venue constructed on the Olympic Park. This case study explores the integration of sustainability into the Aquatics Centre, providing a balanced view of the venue’s sustainability credentials and considering its contribution to the sustainability agenda beyond the boundaries of the Park.

The Aquatics Centre
London’s bid to host the 2012 Olympic and Paralympic Games presented a comprehensive vision for the first sustainable Games. In 2007, the Olympic Delivery Authority (ODA) embodied this commitment in its Sustainable Development Strategy.

The Aquatics Centre’s design featured in the bid, with an iconic wave-like roof defining the gateway to the Park for the majority of visitors.

Temporary seating structures provide a 17,500-seat Games-time capacity for the venue. After the Games these are replaced by a 14-metre-high cantilevered glazed curtain wall, reducing capacity to a legacy-appropriate 2,500 and flooding the interior with natural daylight.

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Images showing Games-time mode (left) and legacy mode (right)
The Aquatics Centre also integrates a 45m wide bridge, responsible for providing Park access for over 750,000 Games spectators. Post-Games, the bridge will be reduced to 14m, better suited to accommodating legacy visitors.

The requirement to accommodate the temporary seating necessitates a main pool hall with a much larger volume and greater external wall area than any existing facility, representing a significant challenge to achieving energy efficiency in use. It is also the most water-hungry venue on the Park, representing over 23 per cent of the estimated baseline water demand during the Park’s 25-year life-cycle.

The Aquatics Centre’s site is the most constrained on the Park, with a live railway to the east and the Waterworks River to the west. These constraints led to the parallel alignment of the three pools within the Aquatics Centre, as it was the only way they could fit on the site and accommodate the required seating numbers.

To add further complexity, underground power lines carrying electricity to east London run under the length of the Aquatics Centre and a high groundwater table exerts a significant upwards force on the pools.

The venue requirements and site constraints led to a heavy-weight design which meant that reducing the embodied carbon and impact of materials used within the structure was a priority.

Integration of sustainability into project delivery
The informed client
The ODA and CLM, the Delivery Partner, invested significant resource to ensure they were an informed client in all areas of project delivery, including sustainability.

The Aquatics Centre was allocated a single point of contact within the core Delivery Partner Sustainability Team to provide guidance, technical support and assurance for the project’s duration. Mentoring enabled development of strong working relationships and mutual respect between the client, the design team and the contractor. These relationships were supported by clear processes that embedded sustainability into design, procurement and construction.

Sustainability objectives were translated into design briefs and detailed design guides. The objectives featured in the tender process for a principal contractor which were subsequently translated into clear contract requirements. However, contracts were not relied upon to deliver sustainability. The client held regular workshops and progress meetings with the project team, providing technical support and guidance throughout the complex process of delivering sustainable construction.

An integrated team
Balfour Beatty were awarded the design and build contract in March 2008, swiftly followed by the introduction of the Zaha Hadid and Arup design team. To improve communication within the project, the contractor and the Delivery Partner agreed to share significant project management resources and, in June 2008, co-located onto the site.

Complete transparency in information sharing and the optimisation of staff resource has led to a unique client/contractor relationship. The supportive relationship, focused on achieving a common and challenging goal, streamlines the project management process.

Supply chain and stakeholder partnership
The contractor appreciated that achieving sustainable construction would require a rethink in how procurement and the supply chain were approached. Although many aspects of sustainability had been clearly integrated into the design and specification, designers cannot be experts in all construction methods and materials.

The procurement team required a clear basis for supply chain engagement that sought innovation and awarded contracts to the best-value solution.
Sustainability Action Plans
The contractor developed a unique solution for managing sustainability from design through to construction.

A work package-based tool was developed that enabled broad-level objectives to be translated into specific opportunities and assigned to package managers. Package managers could then discuss requirements with the design team, translate opportunities into subcontractor tender packages and invite innovation from the supply chain. Decisions could be made with full knowledge of the subsequent sustainability impact.

The outcomes for each work package were logged, the resultant Sustainability Action Plans (SAPs) providing a comprehensive record of stakeholder and supply chain engagement. Simplifying sustainability to this extent enabled ownership and accountability.

The SAPs were further reinforced through adaptation of the contractor’s existing procurement processes. The clarification of specific environment and sustainability at the start of procurement and the inclusion of sustainability in all tender meetings is now an embedded requirement.

Supply chain and stakeholder engagement
The sustainability ambitions of the project were communicated through contractor-led supply chain workshops. These full day events were later replaced by quarterly leadership meetings which focused senior management attention on past sustainability performance, innovations and good practice among subcontractors, new policy requirements and forthcoming risk areas.

Environmental challenges including major excavations of contaminated ground, extensive dewatering, and construction adjacent to and spanning over the Waterworks River were approached in partnership with the regulatory authorities.

Environment-critical method statements were discussed with authorities prior to works starting on site, and site progress reviews were subsequently undertaken. This proactive, collaborative approach to managing construction activities resulted in environmental excellence, process efficiencies and significant learning.

Assurance and reporting
Design assurance
Formal client design reviews, addressing specific sustainability requirements, were undertaken at the concept and design development stages. As the volume of design documentation increased, these formal reviews were replaced by regular monthly design progress meetings.

Construction assurance
The contractor supported regular client-led site inspections and submitted sustainability data on a monthly basis via a client-designed, web-based system. This reporting and review was augmented by biannual, client-led environment and sustainability audits of contractor systems and data.

The contractor approached these inspections and audits as a learning exercise; an opportunity to improve their systems and acquire knowledge on innovative solutions implemented by other projects on the site.

Realignment of the conventional client/contractor relationship from regulatory to collaborative and demonstrable project leadership in environmental issues was critical to delivering cost-effective sustainability.
**Project successes**
The design intent for the Aquatics Centre was formulated before the London 2012 sustainability journey was clearly mapped. As the most complex of the venues, design had to continue apace in parallel with the ODA defining their sustainability vision and setting targets.

Early proposals for a timber constructed roof were discarded as the clear open spans and sightlines required by the design brief were not achievable with a timber construction.

The final 3,200 tonne steel roof has been refined to ensure each member operates at 90 per cent capacity and a 10 per cent reduction in roof area is credited to the relocation of the training pool to beneath the pedestrian bridge that connects the Park to Stratford City.

While it is important to acknowledge the challenges faced by this project, focusing purely on the early planning and design intent does not credit this iconic venue’s sustainability contributions.

**Material innovations**
The Aquatics Centre demonstrates how a pragmatic approach to supply chain engagement and material selection can significantly influence the sustainability credentials of new build.

**Ready mix concrete**
The contractor’s Aquatics team were the first on the Park to push coarse aggregate substitution beyond 50 per cent – to 76 per cent – and the first to pour visible concrete with aggregate replacements. They also undertook numerous trials to establish the maximum ground granulated blast-furnace slag (GGBS) cement substitution that could be achieved while still maintaining a world-class concrete finish. GGBS, a waste by-product from the steel industry, contributes to lower embodied carbon concrete.

The images below illustrate the outcomes of some of these trials. Following numerous trials using from 70 per cent to 30 per cent substitutions, the team finally settled on a 40 per cent cement substitution for the high specification visible concrete. Other elements of visible superstructure concrete were poured with 55 per cent and 70 per cent GGBS substitutions.

Left: Concrete finish quality issues at 70 per cent GGBS replacement
Right: Approved finish surface, achieved without any rework at 40 per cent GGBS replacement and 76 per cent coarse aggregate replacement
The Aquatics team demonstrated that mix design is not the only contributing factor to achieving an excellent concrete finish – collaboration between design team, sub-contractor, concrete supplier, formwork and form release agent suppliers is equally important.

The complex nature of the Aquatics Centre’s superstructure concrete and the finish achieved set an excellent precedent for follow-on projects. Instead of retaining knowledge for competitive advantage purposes, the contractor’s mature approach recognised the need to share best practice with other contractors to achieve excellence in sustainability.

The use of stent on the Aquatics Centre also helped raise the profile of secondary materials across the construction industry. The Park’s concrete supplier have reported a significant increase in enquiries for stent coarse aggregate substitute.

Over 150,000 tonnes of concrete was used in the Aquatics Centre and the integrated pedestrian bridge. The dedication of the team in maximising the sustainability of the concrete achieved over 4,000 tonnes of embodied CO₂ savings and substitution of over 29,000 tonnes of primary aggregate, equivalent to 28 per cent of the total.

The Aquatics Centre was awarded an innovation credit under the Building Research Establishment’s Environmental Assessment Methodology (BREEAM) assessment in recognition of their contribution to sustainable concrete construction.

Forest Stewardship Council timber
At concept design, the architect’s intent for a timber ceiling and external cladding were well-developed. Preference for Red Louro, a Brazilian hardwood, was indicated due to its durability and natural resistance to graffiti and fire which eliminates the need for harsh chemical treatments.

An independent review of sustainable sources of Red Louro highlighted insufficient quantities of sustainable timber to meet the Aquatics Centre’s demand of 485m³. This knowledge, obtained over a year before timbers were installed on site, allowed the contractor to challenge their supply chain to resolve the issue.

Alternative timbers were not considered technically or architecturally appropriate. The selected supplier, proposed a solution combining an internal Red Louro veneer on birch plywood with solid Red Louro external cladding. The validity of the proposal was independently tested.
This innovative proposal enabled the ceiling to be delivered with 50 per cent less Red Louro, all sourced from a credible Forest Stewardship Council (FSC) supply, while retaining the original architectural intent.

In addition, the laminate solution enabled the replacement of 40 tonnes of secondary steel with Kerto structural timbers and permitted pieces to be fully prefabricated off-site with minimal wastage or energy-intensive steam treatment. The resultant cost savings from this initiative are approximately £140,000.

**Recycled engineered fills**

Due to the complexity of the site validation process, required because of the extensive remediation works undertaken on site, the Aquatic Centre was one of the few projects to import large quantities of recycled aggregates for use as engineered fill. To meet planning conditions the Aquatics team developed a detailed tracking and placement system which was subsequently adopted by the Delivery Partner and rolled out across the site.

In total, over 80 per cent of the 235,000 tonnes of loose aggregates used were from a recycled source, a significantly higher percentage than any other venue on the Park.

The majority of recycled aggregate was construction and demolition waste from elsewhere in the London area. A further 23,000 tonnes was obtained from the site-wide soil hospital which created blended engineering materials from the soil-washing remediation process.

**Phthalate-free poly-vinyl chloride**

In response to the ODA’s poly-vinyl chloride (PVC) policy, the Aquatics team reviewed alternative materials for the proposed 19,000m² temporary stand enclosure.

As a result, an innovative, flexible, phthalate-free PVC wrap was installed at a £30,000 cost premium. The installed wrap addresses some of the human health concerns surrounding PVC use but unfortunately, as with conventional PVC fabrics, the ODA policy requirement for 30 per cent recycled content could not be achieved due to technical performance constraints.

It is the first time this material has been used in this form. Earlier uses of flexible wrap on the Basketball Arena and Olympic Stadium’s roof used conventional PVC fabric, containing phthalates.
Energy efficiency
The Aquatics Centre achieves a 15 per cent improvement over 2006 Part L building regulations through a range of measures including:
- optimisation of the main roof geometry to balance the benefit of passive solar heating and the risk of summer overheating;
- enhanced building fabrics, air tightness and solar shading;
- dimmable pool hall lights which respond to natural daylight levels;
- heat recovery in ventilation systems;
- improved efficiency of mechanical and electrical systems, focused on providing a comfortable environment at the pool and for spectators rather than conditioning the entire pool hall; and
- a low velocity poolside displacement ventilation system to minimise pool water evaporation.

The operational carbon footprint of the building is further reduced by drawing space and hot water heating from the Park-wide district heating network.

Figure 1 illustrates how these initiatives improve performance against a notional modelled building and also details how the Aquatics Centre performs in terms of energy consumption against other equivalent pool halls.

Figure 1: Estimated annual energy consumption comparison

Note that the energy in use profile is obtained from the Part L energy model. These values do not reflect the real energy consumptions in the actual building but provides a basis for comparison.
Natural ventilation in temporary stands
The Aquatics Centre also employs an innovative solution to reduce energy consumption during Games-time operation.

Detailed thermal modelling and elemental redesign of the 15,000-seat temporary structures enabled mechanical cooling to be entirely eliminated.

The resulting carbon saving during Games-time operation is approximately 56 tonnes and the resultant cost saving over £250,000.

Ammonia chillers
In early 2009, the ODA was put under considerable pressure to eliminate hydrofluorocarbons (HFCs) from permanent cooling systems. Preference for ammonia or hydrocarbon chillers was indicated due to the significantly lower global warming potential of the respective coolants.

A total equivalent warming impact (TEWI) assessment for the Aquatics Centre indicated a marginal 25-year life-cycle global warming benefit of 130 tonnes equivalent CO₂ through substitution of HFC chillers with ammonia chillers; equivalent to the energy consumption of approximately one and a half typical UK households.

A decision was subsequently made to proceed with ammonia chillers. At a cost £500,000 it is questionable whether the decision reflected value for money or if investment in other sustainable technologies could have delivered a greater carbon saving.

Water efficiency
The Aquatics Centre, although it has a higher potable water demand than all other venues, has achieved a 32 per cent reduction in potable water demand; an equivalent 25-year life-cycle saving of almost 450 megalitres. Most of this reduction has been achieved through the specification of low-flow fixtures and fittings (see Figure 2), nine-litres per minute flow showers, five litres per minute flow taps with auto off controls and 4.5l single-flush toilets.

Greywater recycling
The Aquatics Centre could not be connected to the site-wide non-potable water network due to insufficient space in the service corridor connecting the venue to the main site.

Alternatively it employs a £53,000 greywater recycling system to exploit the vast quantities of wastewater produced through the filter-backwashing process. Approximately one third of this process water, 67.5 megalitres, is treated to a non-potable standard to meet toilet and urinal flushing demand, substituting mains water use.
Rainwater harvesting
The inclusion of a rainwater harvesting system to top-up evaporation losses in the pools was considered. Although discounted due to insufficient plant space and cost, a smaller rainwater harvesting system was subsequently installed to meet the irrigation demands of the green roof on the chiller compound.

Sustainable transport
In accordance with the ODA’s sustainable transport remit, the Aquatics team brought over 55 per cent, almost 200,000 tonnes, of their key building materials, by sustainable transport means, eliminating over 20,000 vehicle movements on local roads.

Aggregates accounted for the majority of these deliveries; however the team also imported 2,000 tonnes of precast concrete bridge decks from Derby and 220 tonnes of pool tiles direct from the Italian manufacturer, by rail.

The rail head operator offered a complete transportation solution from manufacturer to venue. Early engagement with contractors and the supply chain proved critical in raising awareness and overcoming logistical concerns around rail delivery.

The contractor encouraged cost-competitive rail delivery by asking the supply chain to include proposals for rail deliveries within their tender returns, not as a sustainable alternative, but as a core requirement of the tender.

In addition, the contractor recognised the value of rail delivery. On the space-constrained site, rail transportation of programme-critical goods reduced programme risk as the rail head operator offered a storage and call-off service.

The contractor’s Aquatics team also trialled barge deliveries, delivering 700 tonnes of rebar and lightweight aggregate to the site. Unfortunately the trials were not successful due to the physical constraints of the adjacent waterway.

Site management
The construction team faced exceptionally challenging environmental constraints. The Aquatics Centre site is located on one of the most contaminated zones of the Park, bounded by a live railway line and the Waterworks River, with a water table just four metres below the ground.

A brief learning and improvement period swiftly led to a site operating at exceptionally high environmental standards. The commitment to continual improvement is recognised through the achievement of consistently high Considerate Constructor Scheme (CCS) scores and further supported by the presentation of a CCS Gold Award in 2011, the certificate noting the ‘exemplary site was a credit to the aims of the Considerate Constructors Scheme’.

Figure 2: Aquatics Centre lifetime mains water demand

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Salvaged timber was manufactured into vegetable planters for local schools and lengths donated to a local urban farm to construct raised beds. Wooden pallets were also stockpiled for collection, refurbishment and resale by a local company.

Senior management support, empowerment of the Environment Manager and thorough training of site operatives, with time taken to explain intended outcomes of procedures, were critical to site environmental excellence.

Site waste management
The contractor allocated a dedicated area for waste management within the constrained site boundary. The facility, constructed on a concrete base, allowed secure on-site sorting of waste by a dedicated team. Satellite segregation facilities were also provided closer to the workface to encourage operatives to segregate their waste.

This exemplar waste management provision has achieved site segregation rates of 64 per cent, resulting in approximately 96 per cent of Aquatics Centre waste diverted from landfill.

Space was also allocated for storing reusable materials. Salvaged timber was manufactured into vegetable planters for local schools and lengths donated to a local urban farm to construct raised beds. Wooden pallets were also stockpiled for collection, refurbishment and resale by a local company. These small contributions raise the profile of construction within the local communities.

BREEAM and CEEQUAL
A considerable testament to the contractor’s sustainability focus is demonstrated through the pursuit of the BRE Environmental Assessment Method (BREEAM) ‘excellent’ and the Civil Engineering Environmental Quality (CEEQUAL) ‘excellent’ assessments despite contract conditions requiring only a ‘very good’ status.

In March 2011 the ‘excellent’ status of the Aquatics Centre was formally recognised although official certification cannot be awarded until the Olympic-site parklands are complete. The CEEQUAL assessment, yet to be validated, indicates that the integrated bridge will achieve an ‘excellent’ overall score of approximately 85 per cent, with the construction element achieving over 90 per cent.

The real Olympic legacy
There are a few process aspects that are fundamental to successful delivery of sustainable development. These include:
- a clear vision supported by defined objectives and measurable targets;
- comprehensive design guidance and defined reporting requirements;
- a value-based tender process supported by on-going technical support and engagement;
- regular monitoring and reporting; and
- replication of these processes through the supply chain.
However, processes alone cannot deliver sustainability. The collaborative relationship between an informed client, contractor and design team and development of a comprehensive understanding of the sustainability agenda across the whole project team were critical to driving the cultural change necessary for delivering sustainable construction. It is not sufficient to rely solely on a well-written contract to deliver a sustainable outcome.

Simplification of the sustainability agenda makes it accessible to all and engenders ownership which translates into a passion to make a small change that contributes to a bigger picture. Individuals on site, in the office, and within the supply chain are all given the skills, understanding and motivation they need to innovate.

It is widely thought that the Aquatics Centre does not represent sustainability-led design; one must look to the Velodrome to understand what design driven by sustainability from the outset looks like. However, the different contexts and the constraints of the site location must be understood to appreciate that both buildings, as with all the venues on the Park, have made significant contributions to the sustainability agenda.

It is not the individual innovation and technologies employed on the Aquatics Centre that are the largest legacy contributor. Although the body of evidence generated around specific initiatives will prove invaluable to the industry, it is the knowledge gain and adaptation of procurement processes within the contractor’s organisation that stands to deliver the largest sustainability impact.

To appreciate the true contribution this building makes to the sustainability agenda, one must recognise the design team’s flexibility in responding to the developing sustainability agenda and the contractor’s drive to challenge conventional procurement and construction processes.

The appetite for engagement, collaboration and learning demonstrated among the team was second to none. From site operatives to the project director, all those who have worked on the Aquatics Centre can eloquently discuss the sustainability agenda and identify how their individual job function contributes to it. The pride in what has been achieved is evident.
References
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