Steel breaks the boundaries

London's latest skyscraper at 20 Fenchurch Street, known as The Walkie Talkie, is expected to reach its full height this month – and composite steel plays a major role in its challenging construction

20 FENCHURCH STREET

RUBY KITCHING

Project 20 Fenchurch Street, London

Developers Land Securities, Canary Wharf Group

Architect Rafael Viñoly Architects

Construction manager Canary Wharf Contractors (a subsidiary of Canary Wharf Group)

Structural engineer Halcrow Yolles

Steelwork contractor William Hare (main structure)

The 38-storey building at 20 Fenchurch Street is the latest architectural icon to appear on London's skyline. Unlike neighbouring 30 St Mary Axe (the Gherkin) and The London Bridge Tower (The Shard) across the Thames, 20 Fenchurch Street does not taper with height. Instead, the building's floor plate flares to achieve a 50 per cent area increase at the top, compared with ground level.

The office building has been designed to take advantage of the volume of space bounded by the site and protected historic sightlines across London.

On the ground, this has the effect of creating more public space around it than is usual for most skyscrapers that are built right up to their site boundaries.

The building is expected to reach its full height this month when its uppermost floor, at level 35, is crowned with a portal frame structure up to 20 m tall. This 1,200-tonne addition will partially enclose the rooftop Sky Garden, a partially glazed restaurant and garden which offers 360-degree views across London. Open plan offices will occupy the building up to level 34.

The building's superstructure is of composite steel and concrete floor construction with steel columns. Around 9,000 tonnes of steel has been used in fabricated box section columns, cellular beams and decking.

Reduced footprint

Double decker lifts reduce the elevator footprint in the building, which means that the services core does not dominate the reduced floor plate at lower levels. Two shuttle lifts serve the Sky Garden.

The north and south elevations of the building have a fully glazed profile, while the east and west elevations feature vertical aluminium louvres, or fins, for solar shading. The position of these fins line up with the steel members which make up the portal frames over the Sky Garden, creating the impression that these lines wrap over the building. The south side of the building, facing the river, is concave and is lower in height than the north elevation, which features a triple-storey space over the Sky Garden. The building's shape, distinctive fins and glazed elevations have earned it its nickname, The Walkie Talkie.

Since the building deviates from the standard cuboid office block shape, construction manager Canary Wharf Contractors' initial challenge was to work with structural engineer Halcrow Yolles to decide where the concrete core should be located.

The core is usually located in the centre of an orthogonal building, which coincides with its centre of mass. At 20 Fenchurch Street, however, the core is located off-centre, creating varying length ▶

The steelwork contractor William Hare began on site in February 2012

CONSTRUCTION NOTES

The building is made up of two basement levels, offices up to level 34, a Sky Garden at level 35 and roof which takes the building to level 38.

Piling on the site commenced in January 2011 at a level 6 m above the existing building's single basement slab level. This basement area had been infilled to support the existing perimeter secant basement wall. Site workers installed pilecaps to the underside of the new lower basement level and a system of props was introduced to support the upper (existing) basement walls while the fill was excavated and lower basement walls constructed.

To maintain a fast-track programme, Canary Wharf Contractors decided that the core and basement had to be built first to allow tower cranes to be built off the top of the core. These cranes would be needed to erect the main steelwork.

"This meant the basement propping system had to be designed to allow for the core to slide up through it," says CWC associate director of construction operations Charlie Paul.

In August 2011, core construction began and was completed by February 2012 when steelwork contractor William Hare began on site.

Deliveries had to be carefully managed to reduce disruption to local businesses and traffic. On the west of the site, Philpot Lane had to be closed between 8am and 4pm to allow deliveries to take place. CWC also took responsibility for deliveries to nearby retailers to ensure the highest levels of safety were maintained around the building.

Delivery of some of the longest aluminium members – the fins – on the east and west elevations took place at night during road closures when they could be safely hoisted up by tower crane to level 35 before being erected.

CWC is part of developer Canary Wharf Group, which has transformed the Docklands area of London. The project is one of the first major buildings to be built by CWC outside of the Canary Wharf Estate.

spans between the core and perimeter columns. To maintain clear spans between core and column and to limit the depth of beams, prefabricated steel I sections of varying thicknesses were specified, installed by steelwork contractor William Hare.

Rational thinking

"We rationalised the shape of the core," says CWC associate director of construction operations Charlie Paul. Instead of accommodating services, stairs and lifts, the building's core only contains stairs and lifts.

He adds: "The services risers are located just east and west of the core and are [separated by] dry-lined partitions. This means that the profile of the core can stay constant throughout the height of the building. As servicing volumes diminish with height, the risers can get smaller, allowing more space to be used as part of the office floor."

With the height of the building and floor-to-ceiling heights fixed and the core off-centre, the challenge for CWC, William Hare and Halcrow Yolles was to find a structural solution that could accommodate the increasing spans higher up the building.

"At second floor level, the beams only span about 11 m between core and perimeter column, but as the building flares out, the perimeter of the building is up to 22 m away from the core," explains Mr Paul.

The solution was to design beams for a maximum 18 m span from core to perimeter column and to make up the remaining distance using a cantilevering beam.

Column design had to support this arrangement. For the lower levels, the curved elevation is achieved by positioning straight columns at a constant angle in four-storey units. The curved appearance is achieved by faceting. Near the top of the building, where the building is more curved, "faceting" is every two storeys.

"We demonstrated to the architect, using 3D modelling, that by following the curve in four-storey increments, the column line might only be about 12 mm away from the original," says Mr Paul.

AHEAD OF THE CURVE

All columns are 70 mm to 100 mm thick plate box sections and are inclined to the vertical with the angle of inclination faceting at intervals up the building.

The splices between these members set the geometry of the façade in addition to transferring the structural forces. William Hare had to design a tapered machined division plate within a single fabricated item between the column splices to capture all of the complex facet geometry.

A welded spigot allowed the upper column section to be lowered onto the splice and bolted into position. Extensive quality control measures were adopted during fabrication to ensure the spigot and box would couple together, leaving minimal gaps. This gave assurance that the correct angles would be achieved in the columns, and being a simple and practical connection, meant that splicing these heavy columns at an angle (even at height) was straightforward.

Steelwork contractor William Hare developed the endplate detail between columns at the faceting node points to ensure the columns were set at the required angle to achieve the curved profile.

The structural design philosophy requires heavily loaded square column sections at the bottom of the building to be fabricated from steel plate up to 100 mm thick. But with shorter floor spans at these levels, the adjoining beams are relatively light. Higher up the building, beam section sizes increase as the spans increase, but with lower vertical loads on the upper levels, column sizes are much reduced compared to lower down the building.

In terms of erection, CWC's aim was to make best use of its experience of tall buildings from the Canary Wharf estate and to build 20 Fenchurch Street to the same high standards of efficiency as a rectilinear building. For Mr Paul, it meant mounting the tower cranes on the core for the entire steel frame build. This put the core on the critical path (see construction notes box).

"We didn't want tower cranes going up through the floors because that would mean you couldn't finish a floor until they were taken down," says Mr Paul.

Three tower cranes were built off the core. After the building is complete, the cranes will help dismantle each other until the last crane standing is small enough to be dismantled and transported by goods lift to the ground.

By rationalising the longer spans higher up the building into a beam spanning from core to column – and a cantilevered section from column to cladding line – CWC could adopt a similar fast-track programme as on many of its tall, rectilinear buildings at Canary Wharf. The method, as described by Mr Paul, is as follows:

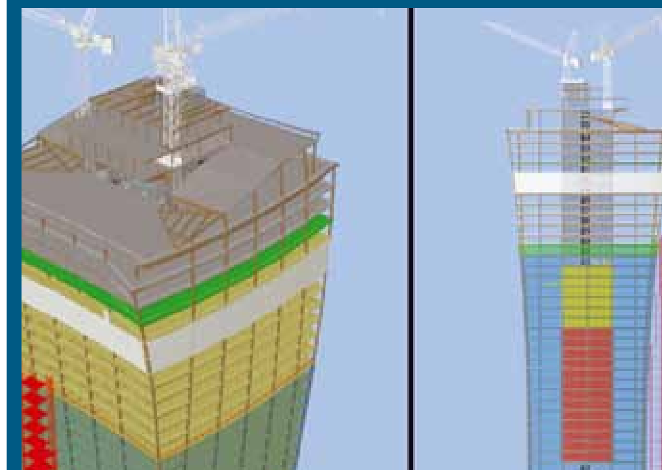
"The steel frame structure is built up to level two using MEWPS [mobile elevating work platforms] at ground level. Decking is then lowered onto levels one and two and the MEWPS are lifted to level two, where it commences building levels three and four.

"We require two floors of overhead protection prior to casting the floor slab, so when we have finished levels three and four, the MEWPS are lifted to level four where erection of steelwork on levels five and six can commence. At this point, levels one and two can be cast and, soon after, fire protection can be applied on level one steelwork. The process means that each trade can complete a floor a week; no one has to wait."

"We've managed to find solutions to deal with all the technicalities borne from the complex shape of this building"

CHARLIE PAUL, CWC

UNDERSTANDING CHALLENGES THROUGH BIM



"The complexity of the building warranted the use of 3D modelling. Using BIM made it much easier for subcontractors to understand the challenges we were facing," says CWC associate director of construction operations Charlie Paul. "Four-dimensional modelling allowed the contractor to tackle construction issues virtually, so that they did not arise on site. It scrutinised the build programme in real time, giving CWC the opportunity to revise methods and make improvements to schedules, often ahead of appointing subcontractors.

"When we were employing traffic management specialists, we could advise them, not only on the numbers and location [of deliveries], we could show turning circles and how various scenarios would have an impact on traffic flow."

So keen was the contractor to explain pinchpoints and the scale of some of the challenges to prospective subcontractors, that during tender interviews, it presented 4D simulations of each subcontractor package of works to explain to tenderers the scale and complexity of the project.

"Activities such as the application of fire protection could be scrutinised on the model and then clearly scheduled in for all contractors to see," says CWC project planner Darren Rackett.

Installation and removal of edge protection in the form of storey-height nets and horizontal fans to arrest any falling debris was also modelled to ensure the activities were programmed to take place in the safest and most time-efficient way.

While edge beams are installed with integral handrails, the netting had to be sequenced to ensure it did not impede concreting and cladding installation. The netting provided additional protection, especially where upper levels of the building stepped over lower storeys.

"4D BIM showed us the windows in time when edge protection could go up and when it could be taken down while allowing work to proceed around it," says Mr Rackett.

4D modelling

Four-dimensional modelling was used to demonstrate the anticipated build and programme – that is 3D building information modelling with time added – as well as the challenges faced by the project to achieve the highest levels of safety and quality (see box, left).

"We used information from the 4D model when we were interviewing bid teams. We showed them the challenges and said, 'go away and find a better solution'," says CWC project planner Darren Rackett.

The upshot was that tenders were returned with very few caveats, despite the fast-track programme, since the brief and its challenges were made so clear at bidding stage. "Commercially, there are huge benefits in using 4D BIM because problems are identified and solved before reaching site," says Mr Paul.

"We've managed to find solutions to deal with all the technicalities borne from the complex shape of this building so that we can build it to a beam and stick programme. We've used lessons learned from previous projects with the best technology available to make it work."

Uplifting buildings

A report from AECOM and the Sweett Group offers guidance on cost-effective ways of achieving a target BREEAM rating. It also suggests that higher ratings can be achieved with minimum expenditure

BREEAM
RUBY KITCHING

BREEAM assessment involves evaluating a building's specification, design, construction and use against established benchmarks according to nine categories. Credits are awarded in each category according to the building's performance, which are then combined to produce a single overall score on a scale of Pass, Good, Very Good, Excellent and Outstanding.

The higher ratings of Very Good, Excellent and Outstanding are increasingly becoming part of conditions set by planning authorities, but can be set by exemplar clients seeking the highest environmental standards.

Research carried out by AECOM and Sweett Group for standard, base case buildings for five building types – distribution warehouse, supermarket, school, office and mixed-use building – has been consolidated to give project teams a helpful starting point for achieving the desired BREEAM rating in the most cost-effective way.

COST UPLIFT TO ACHIEVE A HIGHER BREEAM RATING

Building	Capital construction cost (£m)	Capital cost uplift (%) to achieve BREEAM V good	Excellent	Outstanding
Distribution warehouse	19.4	0.04	0.4	4.8
Supermarket	16.4	0.2	1.8	10.1
Secondary school	22.5	0.2	0.7	5.8
Office	61.7	0.2	0.8	9.8
Mixed-use	36.7	0.1	1.6	5.0

The Target Zero project used real buildings as the basis for each study. As part of the research, the implications of achieving each BREEAM credit were considered and the cost of achieving it determined. Detailed information is contained within the guides published for each building type, but summary schematics have now been produced to give a simple summary of the research.

Measures required to improve BREEAM ratings for a typical office building

Figure 1 (opposite page) is the schematic from the office sector and the project team should first consider the credits in the VG boxes to achieve the lowest cost Very Good rating. If an Excellent rating is desired, then those credits in the E boxes should be added to those in the VG boxes. If an Outstanding rating is desired, then all of the credits must be considered.

The base case for the office study is One Kingdom Street, a 10-storey, steel-framed central London office building. However, BREEAM does not consider the impact of the frame and so the guidance is appropriate for all office buildings, irrespective of proposed framing material.

The schematics are available for each of the five building types at: www.steelconstruction.info/Target_Zero#Breeam_results

How much more will it cost to achieve a higher BREEAM rating?

The table above shows the capital cost increase or 'uplift' for various buildings types (based on case studies) to achieve Very Good, Excellent and Outstanding BREEAM (2008) ratings. The capital costs are based on the most cost-effective route to achieve a higher rating for the base case and its actual location.

In the case of the office building, 0.2 per cent of the capital cost (£123,400) would enable it to achieve a Very Good BREEAM rating and 0.8 per cent of the capital cost (£493,600) could be spent on improving its rating to Excellent.

However, an Outstanding BREEAM rating for the base case office building would require the capital construction cost to increase by 9.8 per cent of the capital cost (£6,017,200).

This is because the majority of these costs relate to achieving a credit that requires a major reduction in CO_2 emissions. This can only be achieved by purchasing and having the facilities for costly onsite power generation such as a wind turbine or biomass boiler, or by using an offsite low-carbon power source.

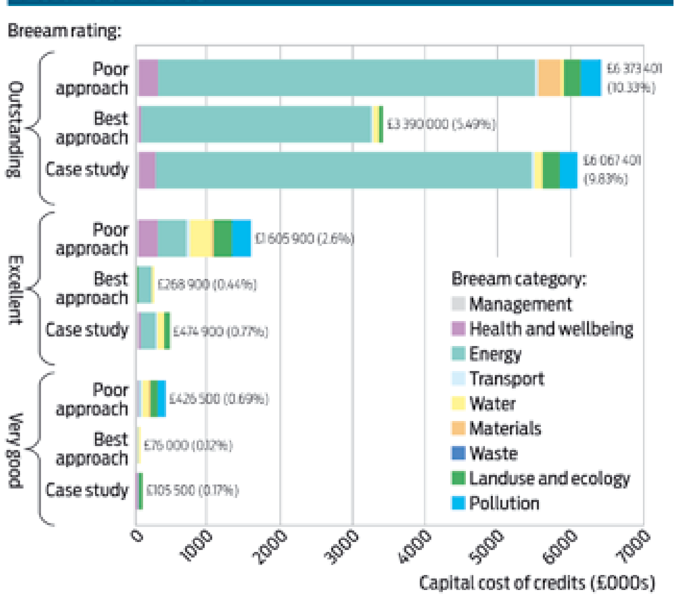
Comparison of cost uplift for different approaches to design for a typical office building

The research (graph, left) compared the cost uplift for different approaches to design for a typical office building, reflecting the influence of location and other factors on the achievable BREEAM score and hence cost. AECOM modelled different scenarios including different locations and site conditions and different design and contractor assumptions.

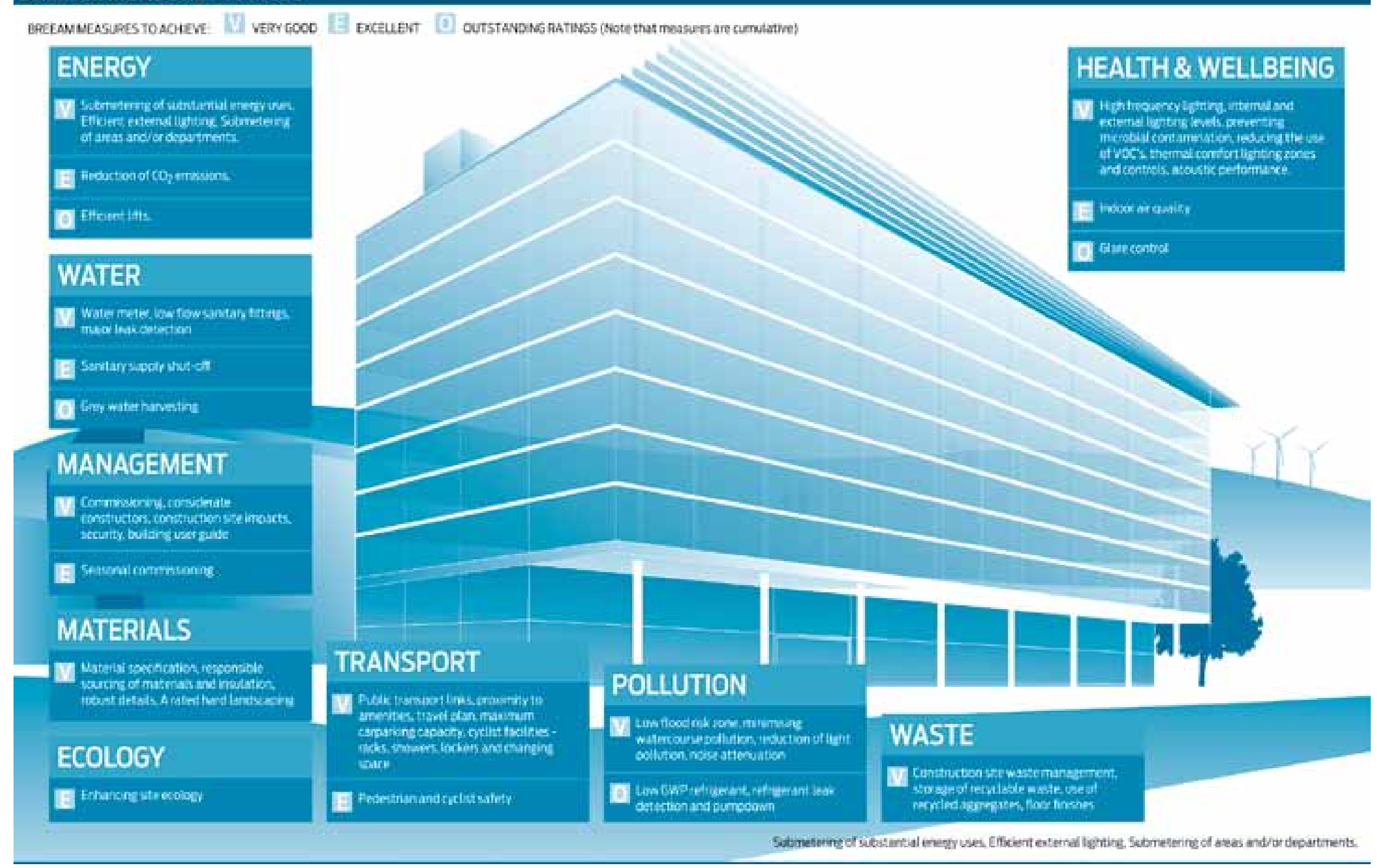
Sweett compared cost uplift for different approaches to design for a typical office building, and found a significant variation in cost depending on whether a 'poor' or 'best' design and construction approach was adopted.

A 'poor' approach is defined as one in which credits are lost when decisions are not taken to pursue them at early stages in the design process.

COMPARISON OF COST UPLIFT FOR DIFFERENT APPROACHES TO DESIGN SCENARIOS



BREEAM MEASURE - OFFICES



An example of an early design decision is procuring an exemplar contractor that is able to achieve contractor-related credits.

The breakdown of cost by BREEAM category is also shown. For an Excellent rating, the uplift cost from a Very Good rating was only 0.44 per cent (£268,900) when adopting a best approach compared with 2.6 per cent (£1,605,900) for a poor approach. To achieve an 'Outstanding' rating, the cost is dominated by the cost of achieving the mandatory operational carbon reduction targets, ie the BREEAM energy credits.

Full details can be found at: www.steelconstruction.info/Target_Zero#BREEAM_results

BREEAM Outstanding

BREEAM assessment involves evaluating a building's specification, design, construction and use against established benchmarks according to nine categories: energy and water use, health and well-being, pollution, transport, materials, waste, ecology and management processes.

Target Zero outlines which areas of a building's design contribute most heavily towards achieving an Outstanding rating, which can cost substantially more if they are not considered early on in the design process.

In crude terms, under the category of 'energy', credits can be awarded for good insulation, more energy-efficient lighting and glazing to achieve a Very Good or Excellent rating, says AECOM sustainability director and Target Zero project director Ant Wilson. "The cost of including these features is relatively small.

But to achieve an Outstanding rating requires a significant reduction in CO_2 emissions under credit Ene 1, which is much more costly. This credit is weighted more heavily than all others and an Outstanding rating cannot be achieved without addressing it."

> **"Target Zero shows that there are different ways of achieving BREEAM credits and how to do so cost-efficiently"**
> ANT WILSON, TARGET ZERO

It is this credit which is responsible for the leap in cost between an Excellent rating and an Outstanding one, as the table and graph demonstrate.

"To achieve Ene 1, could require installing a biomass boiler, which could make the energy efficiency of the building worse. But it would lower the building's carbon content sufficiently to achieve the required BREEAM credits and allow it to achieve an Outstanding rating," adds Mr Wilson.

He adds that for some buildings, achieving an Outstanding BREEAM rating is very challenging. "For many buildings, the location and site have already been decided, so that can take away scope for achieving the most environmentally efficient shape and aspect," he says.

City-centre buildings, for example, often score well since they are close to public transport links, but often have a restricted footprint, leading to a less efficient design.

In contrast, out-of-town buildings on larger, more flexible plots of land may score fewer credits for public transport, but can score better for having a more efficient building shape.

Mr Wilson's team concluded that by adopting the best approach to design leads to cost savings and with greater assurance that the highest ratings can be achieved. "Target Zero shows that there are different ways of achieving BREEAM credits and how to do so cost-efficiently," he adds.

Steel choice for college project

In a technical college in south London, a 1950s warehouse is being extensively refurbished – and using the existing steelwork has facilitated a lighter structural frame to deal with poor ground conditions

ROYAL GREENWICH UTC
RUBY KITCHING

Project Royal Greenwich UTC
Developer Royal Borough of Greenwich
Architect Walters & Cohen
Main contractor BAM Construction
Structural engineer Clarke Nicholls Marcel
Steelwork contractor Bourne Special Projects (part of the Bourne Group)

A £10 million construction and engineering college in Woolwich, south London is being built on the site of a former industrial estate, just a stone's throw from the Thames Barrier. The project involves refurbishing an existing warehouse to provide workshop facilities and building a new three-storey steel-framed teaching block for up to 600 pupils – all within just 12 months.

The institution will be known as Royal Greenwich University Technical College and its aim will be to offer courses related to construction and engineering. Understandably, the client – the Royal Borough of Greenwich – is keen to see the building become part of the learning experience.

Steel on show

"All steel is exposed to show students how the structure was built [so it] relates back to what they are learning in the classroom," says BAM Construction project manager Kevin Stoney.

Part of the project will see a warehouse dating back to the 1950s being extensively refurbished to provide a single-storey area for practical work, including a heavy structures laboratory.

Almost all of the retained steel columns, beams and the roof truss, originally fabricated by Dorman Long, will be retained and strengthened to accommodate heavier roof loads. (see box opposite page). A new canopy to the north face of the warehouse will create a sheltered practical area.

Structural engineer Clarke Nicholls Marcel produced a 3D model of both buildings and with steelwork contractor Bourne Special Projects, identified solutions which allowed as much of the warehouse structure to be reused as possible.

BAM Construction started on the project in February 2012, working closely with the architect and the client to develop a scheme which would fit the budget and allow it to be built in a single academic year.

The existing steelwork in the warehouse set a precedent for using the material in the teaching block, but it was also an obvious choice because it facilitated a lighter structural frame, says Clarke Nicholls Marcel associate John Matthews: "The ground conditions were poor, so to limit ading on the foundations, the steel option was preferred. Using a reinforced concrete frame would have made the building heavier, requiring bigger pile sizes [diameters] and lengths, which would have ended up costing more than a steel-framed solution," he says.

BAM Construction favoured a steel frame and precast concrete flooring solution as it offered programme advantages due to elements being prefabricated off site.

The braced steel core in the teaching block was prefabricated and lifted into position as a single 9.5-tonne unit

THE SPORTS STUDIO

A clear column free space of 16 x 17 m for the ground floor sports studio in the teaching block has been achieved by hanging the first and second floor slabs from roof steelwork and transferring their loads to foundations via columns around the studio perimeter.

Since the first floor level was fixed by the height of the Woolwich Road and the ground floor slab could not be lowered (due to the risk of moving contaminated soil), a deeper beam section at first floor level could not be accommodated to span the 16 m distance and keep the required room height.

Instead, the studio's column-free space has been achieved via 254 mm x 254 mm column section hangers, which are suspended from twin roof girders running north-south, to support the first and second floor slab over the studio area. These girders are 1,110 mm by 500 mm fabricated sections to support the load of these floors. The beam over the ground floor studio area can, then remain the modest pre-cambered 305 mm x 305 mm column section size.

This solution has the advantage of locating the large foundations required to support the heavy column loads from the transfer system internally and away from the existing warehouse foundations where space is limited.

"Using a reinforced concrete frame would have made the building heavier, requiring bigger pile sizes"

JOHN MATTHEWS, CLARKE NICHOLLS MARCEL

WORKSHOP DESIGN

The original warehouse stability system comprised external and internal masonry shear walls with an absence of horizontal bracing in the roof. For the requirements of the new workshop, internal masonry stability walls and the external north side masonry wall had to be demolished.

To re-establish structural stability, new vertical steel cross bracing replaces these walls. Existing east, west and south side external masonry walls remain.

"The original steelwork from 1957 was in good condition, so could be retained, but the removal of masonry stability walls meant that we had to add several bays of cross-bracing," says Clarke Nicholls Marcel associate John Matthews.

"We were able to keep the roof trusses, but had to add horizontal ties and bracing to transfer forces back to existing external shear walls and the new vertical cross bracing."

ROYAL GREENWICH UTC

In August 2012, five buildings on the 12,000 sq m site were demolished, including a single-storey portal frame building to the west of the warehouse to make room for the teaching block. The remaining site will be converted into two all-weather pitches, a fitness track and delivery area.

The single-storey warehouse measures 66 m x 41 m. Its floor, columns, sawtooth roof and most external walls will be retained.

Contamination risk

"Since the ground was known to be contaminated due to the area being a former industrial site, we decided to retain the existing ground floor slab in the warehouse. This meant that we managed the risk of contaminated ground," says Mr Stoney. "We also retained the drainage system and [external] brick wall on the Woolwich Road [on the south side of the warehouse] and eastern side."

The three-storey teaching block measures 18 m across the Woolwich Road elevation and is 58 m deep. The erection method involved installing the prefabricated steel framed lift core in a single 9.5-tonne module. Piecemeal, this would have taken two to three days to install according to Bourne's senior site manager Chris Page. The core is braced and supports floor beams in the final case. Until all the steelwork and precast planks have been installed, temporary steel bracing provides stability.

Entrance to the teaching block will be from the Woolwich Road at first floor level. Clear spans for a ground floor sports studio and assembly area have been achieved by incorporating heavy steelwork in the roof (see box opposite page). Classrooms and administrative areas occupy the first and second floors of the block. Extensive glazing on the western elevation will allow views across the parkland area adjacent to the site.

Since the teaching block is enclosed by the Woolwich Road to the south, the warehouse on the east and parkland to the west, access to it is limited to just the north side. Despite heavy snowfall halting operations for three and a half days, the block was completed in just six weeks.

All the steelwork on the teaching block has now been erected and the strengthening work completed in the warehouse, meaning that in the coming weeks, site workers can install the workshop canopy and fit precast planks in the teaching block.