Selfridges, Birmingham

Ed Clark   David Gilpin

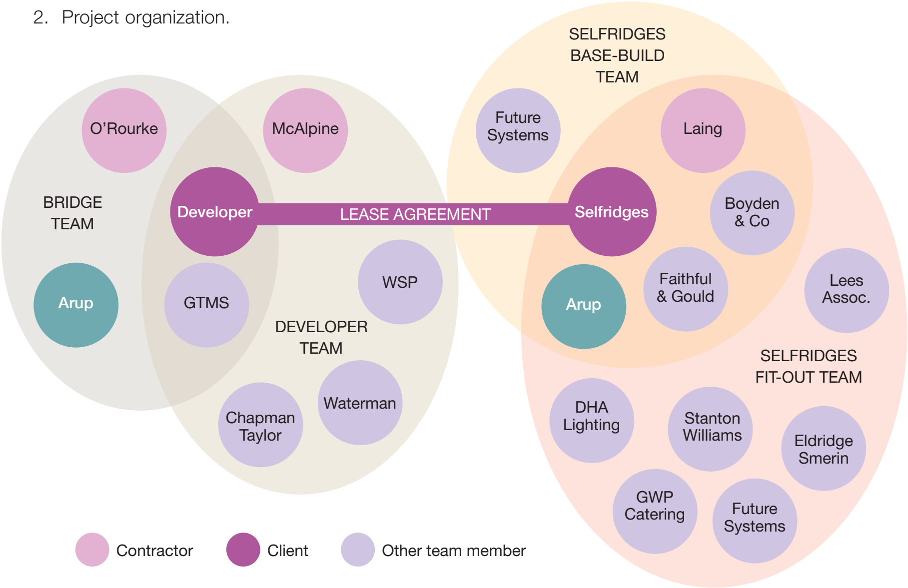
Introduction

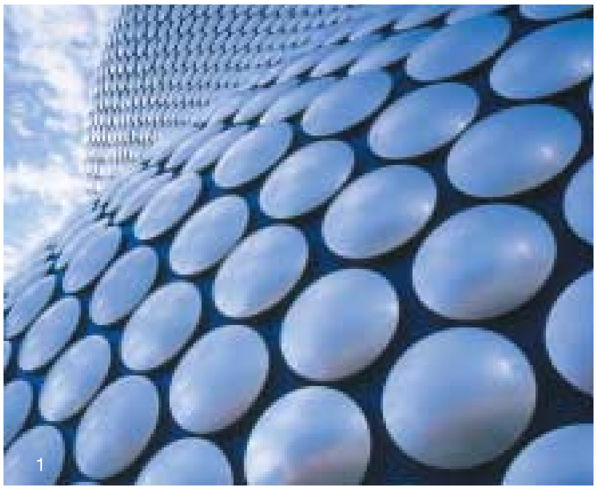
The Selfridges building in Birmingham, England, is the larger of two anchor stores in the newly-rebuilt Bullring shopping centre. Hitherto, the firm had been wholly associated with its famous flagship store in Oxford Street, London, and its decision to expand into new premises beyond the capital was highly significant. Having decided to open its first new-build store in the UK's second largest city, Selfridges made its acceptance of the building tenancy conditional on choosing its own architect to design the complete building, rather than provide only fit-out within a building shell designed by the Bullring architect, Benoy. Bullring's developer consortium, the Birmingham Alliance, accepted this condition and Future Systems, with Arup, was appointed in October 1999.

Future Systems' vision was a building form that would fit the contextually diverse site whilst embracing Selfridges' demand for an internally-focused, windowless box. The resulting unique façade gives scale, texture, and an accentuation of the building curvature (Fig 1). Arup provided full multidisciplinary engineering design: structure, services, façades, fire, communications, and acoustics, with specialist input from Arup Research + Development.

Selfridges' store programme remained inextricably linked with the four-year Bullring development programme, despite having an independent design team. This long timescale and the complex contractual arrangement led to the project being built in several phases. McAlpine, the Bullring main contractor, built the structural frame for the Birmingham Alliance, whilst Laing O'Rourke was appointed directly by Selfridges to construct the remainder of the store including the façade and fit-out – the latter broken down into off-retail and retail phases. The bridge link between Selfridges and the adjacent car park building was procured by the Birmingham Alliance under a third contract on a design-and-build basis. Arup's Selfridges team undertook the engineering design of all three contracts, despite the differing client and contract teams (Fig 2).

2. Project organization.

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Inspired by a Paco Rabanne sequined dress, the Selfridges building glistens in the heart of Birmingham's Bullring.

This phasing had a major impact on the building design, with many decisions taken years in advance of the design and construction of the relevant packages. For example, the four designers for the retail fit-out (one for each floor) were only appointed after completion of the structural frame and tendering of the base-build services, and the bridge detailed design took place only after construction of the structural frame supporting it.

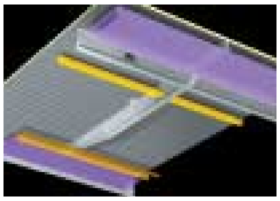
Combining this phasing with the high architectural aspirations, complex brief, and demanding budget, the project was destined to be an engineering and design management challenge from the outset.

The evolution of the resulting highly-integrated and holistic engineering solution under these circumstances added further complexity to the design challenge. However, the close-knit design team saw this as the only way to deliver the client's often-quoted aspiration for an iconic store, and achieved it by commitment and shared vision. The result was worth the effort, with the store opening to critical acclaim, on time and on budget, in September 2003.

Framing option 1:
Regular column grid imposed on irregular plan.

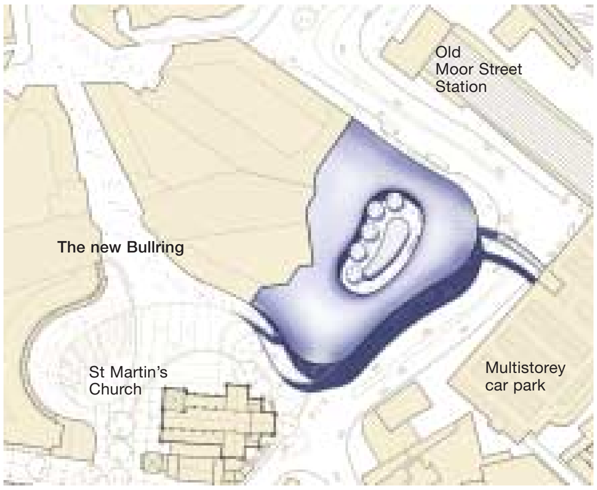
Framing option 2:
Irregular column grid.

4. Conceptual column grid options.



5. Co-ordination of services and structure: 3-D conceptualization.

6. Co-ordination of services and structure: the built reality.



3. Location plan.

Structural steel frame

The primary functions of the frame are to provide a support skeleton for the free-form building façade and to create large, column-free retail spaces of maximum height. To meet these goals, the design embraced CAD/CAM technology and mass customization to allow the irregular framework to be fabricated economically. It also achieves a high degree of integration with the services feeding the retail floors, to maximize floor-to-ceiling heights. Neither strategy was ground-breaking in isolation, but in combination they created a truly holistic solution, an economic synergy of architecture and building engineering that could not have been achieved more conventionally.

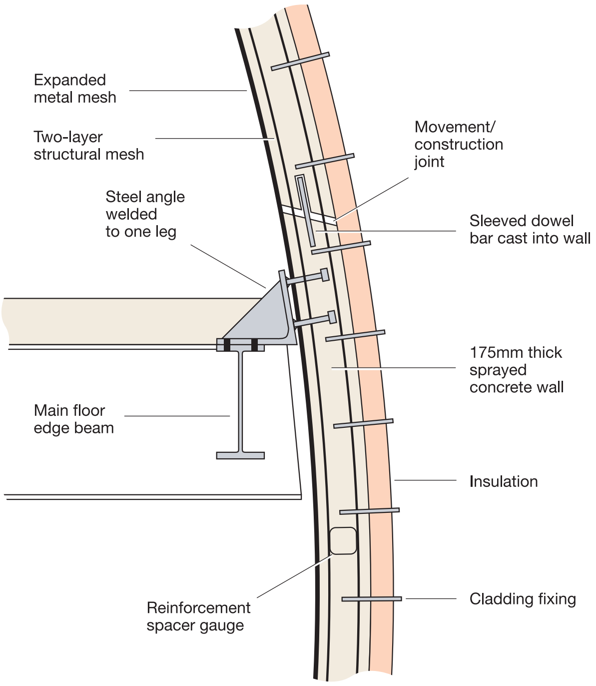
The starting point for the frame design was to derive a suitable column layout. Superimposing a standard cartesian column grid onto the irregular building plan seemed inappropriate and incompatible with the architectural layout, so a string of columns was located around the perimeter, approximately 12m apart, with a separate necklace around the two atria at the same spacing. A handful of extra columns was required to limit primary and secondary beam spans to 12m and 16m respectively - the maximum considered economically feasible. Again, these additional columns were individually and strategically placed to suit both the structural and architectural requirements (Fig 4).

The plan shape of the building changes from floor to floor to match the curvature of the envelope in section. This requires secondary beams to cantilever from the perimeter column line by different distances around the slab edge and at each level. At the 'waist' of the building the columns sit tight against the inside of the façade, whilst at the 'hips' and 'shoulders' the floor cantilevers to the façade by up to 4.5m, deemed to be the maximum practical limit and thus controlling the vertical curvature of the building. It was these relatively long spans and the lack of a regular grid that drove the design towards a steel solution.

A desire for maximum floor-to-ceiling heights in retail areas led to structure and services being integrated within the same 1.5m deep zone. This required a balance of practicality and flexibility, allowing the potential for future rearrangement and refitting of retail departments. The chosen strategy provides fixed routes for primary ductwork through standard notches at beam ends, with secondary ducts and pipework running through 650mm diameter holes in beam webs. These holes are not located specifically for the current services arrangement (indeed this arrangement was unknown until after the completion of the frame erection), rather they were designed to ensure that a reasonable level of variation in layout was possible. This standardization of notch and hole sizes/spacing simplified the fabrication requirements and allowed some repetition despite the many different beam lengths. The co-ordinated structure/services strategy also steered the structural design towards a deep but light beam solution with good stiffness characteristics and hence good dynamic performance. Asymmetric plate girders of a standard depth were chosen for most beam sections, working compositely with the 150mm deep concrete floor slab. Using plate girders allowed greater control over the distribution of material than having equivalent-depth rolled sections, resulting in much lighter beams and less fabrication waste (Figs 5, 6).

7. Atrium steelwork.

8. External view of completed frame.



9. Indicative section through sprayed concrete wall, showing fixing detail.

It became clear during design that the secondary floor beams comprised over two-thirds of the total frame tonnage, and that small improvements in their design would yield significant overall weight and cost savings. The optimization/ rationalization process was complicated by the many different beam lengths and support conditions, resulting in a vast matrix of different demands. The resulting designs and number of different beam types are a balance of performance and practicality (Figs 7, 8).

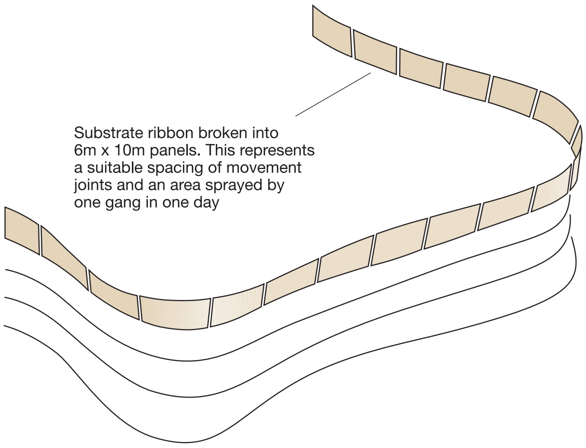
Structural façade substrate

The need to form the curved geometry of the façade without incurring high construction costs presented one of the most complex design challenges. The varying curvature and non-developable shape of the building precluded efficient modularization of structural components or formwork, which prompted the team to look at more homogeneous and unconventional methods of façade construction. Options such as steel mullions, precast concrete, ferrocement, and GRC were investigated, but eventually rejected in favour of sprayed concrete (Fig 9), which could be formed to the required geometry and sprayed to a thickness whereby it could hold its own shape and resist wind loads without the need for a supporting sub-frame.

Expanded metal mesh was used as permanent formwork, bent on site to the required curvature and held in position by an adjustable scaffold system supported on the floor slabs within the building. Four layers of structural reinforcement were then fixed to the formwork, and concrete sprayed from the outside to a thickness of 175mm. The wet spray method was used for most of the substrate, covered by a final 30mm thick dry spray coat using a pre-bagged mix with smaller aggregate to allow a final trowelled finish suitable to receive the spray-applied waterproofing membrane.

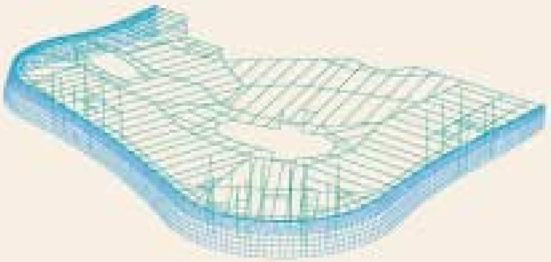
The chosen structural system divides the surface of the façade into storey-height ribbons. This avoids the problems of supporting a 30m high concrete façade around the ground level window openings and off the edge of a retaining wall structure designed and constructed as part of the wider Bullring development relatively early in the Selfridges design process. This decision allowed each storey of façade to be hung from the floor structure above and only laterally restrained at the connection with the storey below. Thus the likely importance of buckling effects is reduced, and the loads from the façade can be associated with a particular supporting floor, simplifying the analysis of the combined structure (Figs 10, 11).

The façade structure was analyzed in GSA using a 2-D finite element model linked to the 1-D element floor plate models built previously to design the main frame. The results from these analyses were used to tune the thickness of the concrete skin to achieve a substrate of adequate strength and stiffness whilst minimizing the load to be carried by the supporting frame. Design of reinforcement requirements vertically and horizontally was carried out by post-processing analysis results using Arup's in-house software RC2D (Fig 12 overleaf).

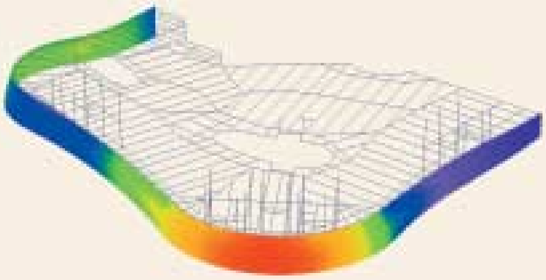


10. Façade substrate panelization.

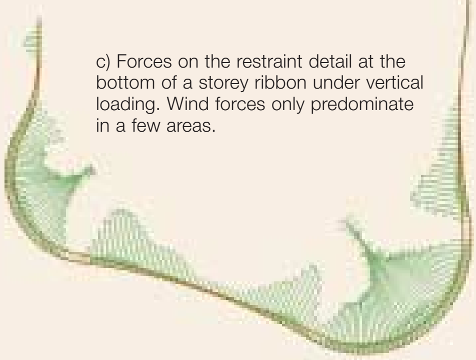
11. Spraying the substrate on site.



a) Combined floor frame/façade model used to study the composite behaviour of the system.



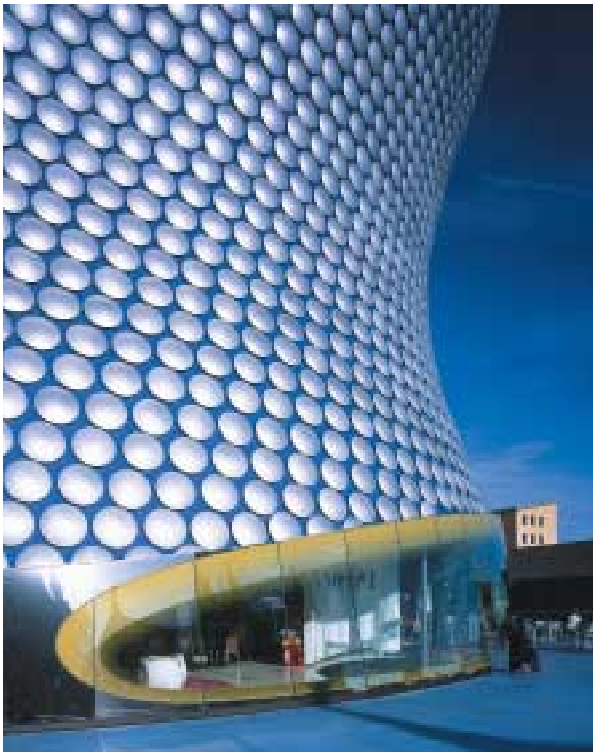
b) Façade displacements around a typical storey ribbon under full loading, showing the extent to which the façade evens out the localized deflections of the supporting steel frame.

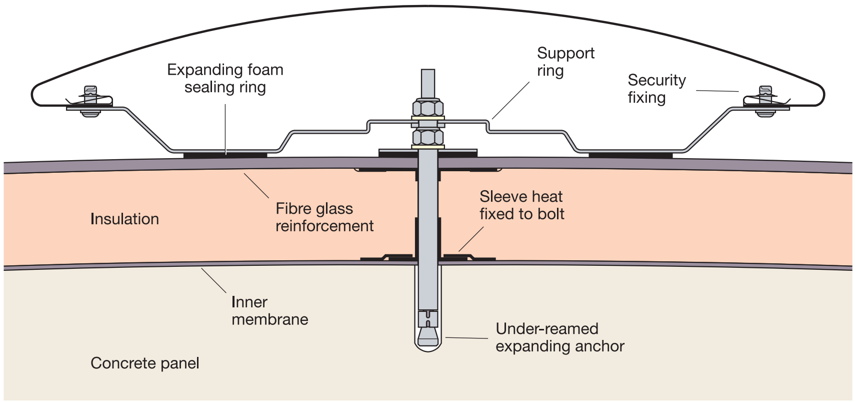


c) Forces on the restraint detail at the bottom of a storey ribbon under vertical loading. Wind forces only predominate in a few areas.

12. GSA analysis of façade.

13. Glazing at terrace-level entrance.





14. Indicative detail of façade construction and fixing.

Façade cladding

The distinctive façade construction covered the sprayed concrete substrate with a liquid membrane vapour barrier, insulation, and an outer, spray-applied, coloured membrane on a glass reinforced render. Finally, the building was clad in 15 000 anodized aluminium discs, each of which went through stringent quality control (Fig 14). The final design of the cladding followed extensive research by the design team with cladding material suppliers. Apart from the technical challenges of cladding such an unusual building, cost control was a major driving factor. Amazingly, the final design is comparable on cost terms with the more traditional metal and glass façades on nearby Bullring buildings.

Point-fixed, laminated glazing with a ceramic frit and mirror-finished border is located around the base of the building and in small windows at high level. The glazing is set into polished stainless steel rainscreen cladding where the public have access to the façade (Fig 13).

In the centre of the building is a lightweight atrium roof. It was detail-designed by Haran Glass and is a suspension structure in which pretensioned rods support the point-fixed laminated glass. The weight of the glass is sufficient to counteract uplift loads, resulting in an extremely light structure.

Extensive structural and weathering tests were carried out on the various cladding systems. These included accelerated ageing of the blue finish, impact resistance of the glazing, and load-testing of the aluminium disks should they prove an irresistible challenge to climbers.

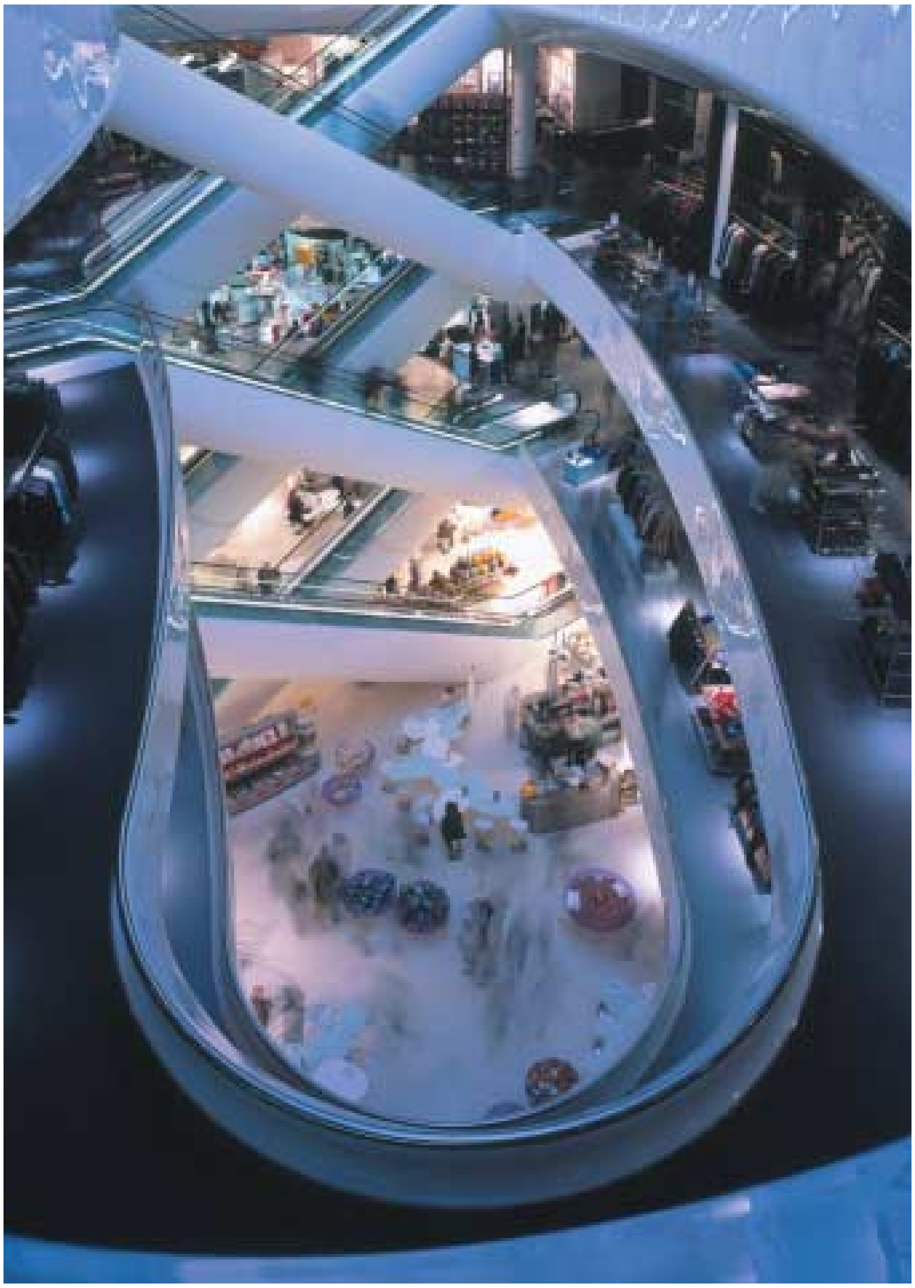
Rainwater from the curved roof and façade is collected by integrated, 'invisible' gutters at the façade 'shoulder' level, where it is brought into the building and connected into downpipes in the cores. Additional gutters are also provided around the windows at entrances and display windows.

Building services strategy

Apart from meeting the budget, three principles governed the design of the building services: comfortable internal conditions, flexibility to accommodate future churn, and energy efficiency.

Some 15% of the retail area fit-out will change each year to maintain the store at the cutting edge of fashion, and this churn will be continuous whilst the store is operational. In response to this, the design team developed a ‘plug-and-play’ system of retail services, with power, air-conditioning, data cabling, lighting control, and building management system (BMS) all available locally in retail areas without the need to access perimeter risers. Central controls are then reprogrammed as necessary.

At the concept stage, computer modelling of the daylight through the atrium rooflight enabled the angle and shape of the atrium to be developed to bring natural light deep into the store (Fig 15).



15. Atrium with the store in use.

Mechanical services

Retail is energy-intensive, with high lighting and design occupancy loads. However, occupancies vary considerably and are usually below design values. As occupancy also drives fresh air requirements, and the Birmingham Selfridges has few windows, the occupancy governs the building energy pattern. Systems were therefore developed that took advantage of the varying loads to provide calculated annual energy savings of over 40%, compared with the standard constant volume retail air system with fixed fresh air percentages and fixed speed chilled water system.

A variable air volume (VAV) system was selected instead of a constant volume system to give savings in fan energy at non-peak loads, and avoid chilled water on floor plates - this was a client request. Eight similar air-handling units on the roof provide air to VAV boxes using low-loss distribution ductwork. The VAV boxes serve swirl diffusers 4.5m above the floor, which were extensively laboratory tested during design to ensure good air distribution at 40% of peak volume. Local temperature sensors provide zone control of VAV boxes.

Full recirculation, with CO_2 sensors monitoring the return air to control fresh air against occupancy, reduces peak heating and cooling loads. Free cooling using 100% outside air is employed when the external temperatures make it more energy-efficient. Perimeter heating was separated from the VAV system to avoid the need for terminal reheat, and reduce cost and complexity.

The size and routing of primary ductwork was optimized with the structure as already described. The final routing of fit-out ductwork from VAV boxes was co-ordinated with the structural beams using as-built structural 3-D models from the steel fabricator transferred onto layout drawings, ensuring co-ordination and saving considerable time on site. Complex areas of services behind the curved skin were modelled in 3-D (Fig 16).

Off-retail areas are provided with minimum fresh air using dedicated air handling units, with local fan coils providing heating and cooling. The staff restaurant uses an all-air, constant volume system to provide comfort cooling and make-up air for kitchen extract. Kitchen extract fans are also provided to the cooking islands in the food hall and to restaurant kitchens.

The chilled water system uses a two-speed primary circuit that switches out half of the air-cooled chillers when not required, saving considerable pumping energy. Variable speed, two-port controlled secondary circuits further reduce pumping costs. Temperature rescheduling allows fan coils in back-of-house areas to use 11°/17°C water temperatures at night and in winter, significantly increasing the coefficient of performance. Separate, direct exchange cooling is provided to the main communications and security rooms.

Central boilers were removed as a cost saving early in the design. The low supply air temperatures and use of recirculation mean that electric heater batteries in the retail air-handling units are seldom used, providing significant cost savings over a central system.

16. 3-D modelling of services and structure.

Public health

Central hot water generation is not provided. In line with the 'plug-and-play' strategy, local storage heaters are sized and controlled to meet local needs and power can be metered for billing to concessions. The change between base-build predictions and confirmed fit-out catering requirements demonstrated the benefit of this approach.

Cold water and gas risers with capped connections to each floor are provided around the building to meet future fit-out catering demands.

Extensive gravity drainage connects the food hall and other areas to the sub-slab drainage system, co-ordinated early on with the Bullring team to avoid the need to use sumps.

Electrical systems

Power for the store comes from two independent HV rings serving the Bullring development. One serves two 1250kVA transformers that provide the non-essential loads, whilst the other, from a different sub-station in Birmingham, serves a 500kVA transformer that provides a standby supply for essential and life-safety systems, avoiding the need for a stand-by generator.

Panel boards with metering facilities serve 160A three-phase busbars and a modular wiring system at high level in the retail area. All general retail power is taken from tap-offs connected to the busbars, whilst 'landlord equipment' - VAV boxes and security equipment - uses the modular wiring system that can be served by the emergency supply. This simple system provides 'plug-and-play' power, as retail fit-out only needs access to the local busbar, not to the risers. Tap-offs can be metered for billing of concessions.

17. The bookshop, showing services integrated with structure.

18. The impression of well-lit spaciousness pervades the store.

Whilst most retail power is required at high level, tills and shop-fit lighting require power at low level. Raised floors were originally included, but removed as a cost saving. Power to low level is provided by connecting a tap-off to the busbar in the ceiling of the floor below, and drilling through the slab.

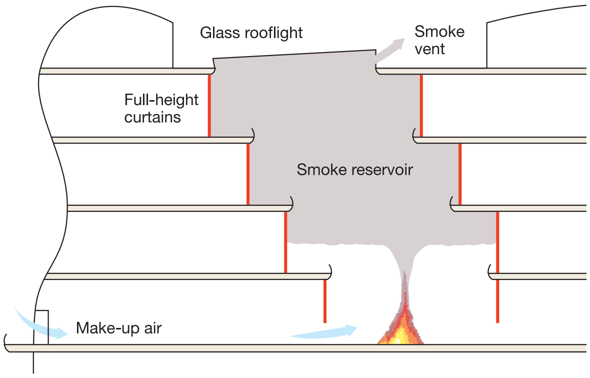
Much of the building power load is associated with lighting, and a modular lighting control system was an essential client requirement. A system of three basic levels of retail lighting was developed - security lighting, general/cleaning lighting, and display lighting which is only on when the store is trading. In addition, scenes can be set as required to cater for special functions and events. Back-of-house lighting is controlled independently. Modules on the floor plates control both the lighting at high level and the floor boxes that serve low-level display lighting.

There is no central battery or UPS system. Emergency lighting throughout the store is provided by local battery packs, whilst local UPS units supply back-up power to tills on retail floors and to the central communications room. This strategy maintains flexibility and reduces complexity and capital cost.

Security is an essential element; there are systems for access control, intruder alarm, merchandise protection and CCTV, interfaced with other systems as required. Article tag sensing is buried under all exits from the retail area, maintaining security without compromising the store's visual impact.

The 12 escalators in the curved atria add drama, and afford the main customer circulation routes around the store. Two double-sided customer lifts connect the retail floors to the bridge and street-level entrances. The three fire-fighting lifts were used to minimize space requirements and co-ordinate with the curved roof of the building; all the machinery is contained within the lift shaft, avoiding the need for additional machine space.

Two goods lifts provide separate goods-in and goods-out routes to all floors from the loading bay level via different cores. Space has been allowed for an additional goods-in lift and an additional passenger lift.



19. Smoke control strategy: atrium fire scenario.

Fire engineering

The two atria and the entrances into the rest of the Bullring shopping centre enhance the feeling of space and openness, and to enable this without compromising safety for staff and public in the event of fire, a holistic fire engineering approach was adopted. It has two innovative aspects.

The base of the main atrium is used as retail space (currently the food hall) and the usual way to allow this to happen would be to have sprinklers controlling the size and spread of fire. Instead an alternative approach was taken, to have ‘islands of combustible load’. The amount of combustible load within each ‘island’ is limited to control the size of fire, and the islands are separated from each other by sufficient distance to prevent spread. Smoke is extracted naturally via the atrium roof. This ‘islands approach’ required Selfridges to stick to quite strict guidelines when placing retail displays within the atrium base, but they were happy to accept this.

The second innovative aspect is that a mechanical smoke control system, using the air-conditioning extract ductwork, keeps the smoke layer above head height, maintaining a clear escape zone for occupants. This allowed for an increase in the allowable evacuation time from the building and hence a reduction in stair core sizes. To support the smoke control strategy, curved drop-down curtains around the two atria prevent smoke passing from one floor to another, or from escaping from the main atrium in the event of a fire there. The main atrium is canted and so the smoke curtains had to be carefully located (Fig 19).

Selfridges is independent from the rest of the Bullring in fire-protection terms, with side-operating fire shutters providing two-hour fire separation to the mall at each level. These close if a fire is detected within the store to prevent fire spread to other parts of the Bullring and to prevent people entering the store during an evacuation. On the other hand, if there is a fire elsewhere, Selfridges can continue trading.

The store has an L1 fire alarm system and a voice alarm/public address system to support the early detection of fire and early initiation of evacuation needed to support the extended evacuation time. The whole building operates as a single fire zone for evacuation purposes. The alarm system is interfaced with the Bullring so that information of fire status can be shared.

Sprinklers are distributed throughout the store except for the atria. The large atrium is treated as described above, whilst the small atrium base is considered a sterile zone with no combustible contents. Water storage and sprinkler pumps are provided centrally within the Bullring, optimizing space in the development.

A reduction in structural fire rating from 120 mins to 90 mins was allowed, based on the provision of sprinklers and the number of floors being less than would normally be expected within the height of the building, due to the large floor-to-floor heights.

None of the fire engineering approaches adopted would have been possible without the good relationship established with the supportive (and patient) local authority team.

Communications

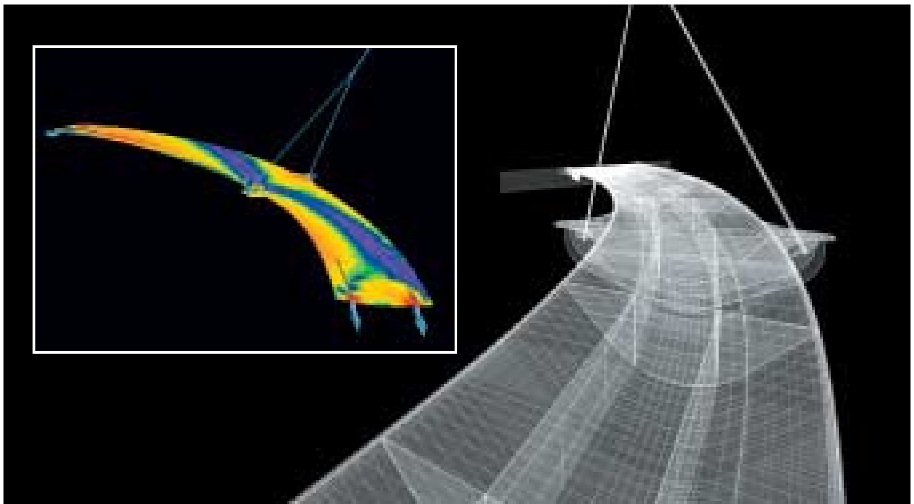
The communications strategy continues the 'plug-and-play' approach to retail servicing, whilst providing network resilience to the store's IT systems. From equipment rooms on all floors, cabling serves a grid of floor distribution points - groups of outlets mounted together to act as a local point for final connection to tills and other items. The structured cabling system also provides cabling for the BMS network on the retail floors, avoiding the need for parallel cabling infrastructure systems. It is believed to be the first time such a system has been used in a retail environment.

The bridge

The design of the 37m span footbridge linking to the Moor Street Car Park was driven by the architectural aspiration for an elegant form with a clear relationship to the Selfridges building. By using the structure as an exposed sculptural surface the design team could minimize the deck depth and avoid the need for additional cladding. The bridge is a steel box girder with internal stiffeners, curved both on plan and elevation, akin to an aeroplane wing. Further support is given by cable stays tied back to the Selfridges frame at roof level.

A 3-D model was produced in Rhino to demonstrate that the deck could be fabricated entirely from warped but developable steel plates and segments of bent tubes. This model was also used to produce developed cutting patterns for the warped surfaces and to extract all other fabrication information. The bridge was analyzed in GSA using a 2-D finite element model derived from the Rhino geometry, and detailed design carried out to *BS5400* by slight adaptation of clauses intended to justify conventional rectilinear box girder sections (Figs 20 & 21).

20. Rhino model and 21. (inset) GSA analysis of the bridge.



22. The completed Selfridges store and its link bridge in their Birmingham setting.

The bridge is covered by a polycarbonate canopy supported off a series of T-section steel arches at varying angles of inclination, supported in turn by the bridge deck and restrained laterally out of plane by connection to a continuous handrail. The cross-sections of these arch elements vary continuously, allowing the tops of the Ts to lie parallel to the freeform canopy surface whilst the stems remain in the inclined plane of each arch. For this reason the arches were also built up from plate with developed cutting patterns for the top plates generated from the Rhino 3-D model.

Conclusion

Selfridges Birmingham is a grand gesture of a building and a testament to the vision and courage of client and design team alike. Whilst no wholly new engineering technologies were developed, the innovation came from challenging convention in every area and wholeheartedly embracing multi-disciplinary working. Where standard solutions were appropriate they were used; where they were not, new solutions were found or transferred from other applications.

If this building has a hallmark, it is in the design team's approach of uncompromisingly pushing what can be done one step further. The result is a well-co-ordinated but flexible building, delivered on time and on budget. Selfridges has transformed the appearance of Birmingham's much-maligned centre, and now provides an experience that has redefined department store shopping. It will undoubtedly lead to other buildings 'borrowing' the techniques and solutions of which it is composed, and is fast becoming an icon for the city.

Awards

Concrete Society Outstanding Structure Award / Institution of Civil Engineers Regional Award / Royal Fine Art Commission & BSkyB Retail Innovation Award / Royal Institute of British Architects Regional Award / Structural Steel Design Award

Credits

Client: Selfridges & Co/Birmingham Alliance/O'Rourke Civil Engineering (bridge link) **Architect:** Future Systems **Retail fit-out architects:** Future Systems, Eldridge Smerin, Stanton Williams, Cibic/Lees Associates **Structural, building services, fire, façade, acoustics, and communications engineer:** Arup - Peter Bailey, Jacqueline Barnes, Simon Barden, Colman Billings, James Bishop, Anna Broomfield, Stuart Bull, Tony Campbell, Ed Clark, Ida Coppola, Emmanuelle Danisi, Jim Deegan, David Easter, Steve Evans, Suzanne Freed, David Gilpin, David Glover, Warrick Gorrie, Peter Hartigan, John Heath, Rachel Hughes, Paul Hyde, Roy James, Adam Jaworski, Bob Jones, Kieron Kettle, Ken Kilfedder, Brian Lake, Paul Malpas, Paul Marchant, David McAllister, Chad McArthur, Jon McCarthy, Simon Morley, Ed Newman-Sanders, Chris Peaston, Anthony Proctor, Oliver Riches, Ian Rogers, Adrian Savage, Andrew Sedgwick, Jim Smith, Edwin Stokes, Edward Tricklebank, Lee Van Achter, Paul Verdi, Terry Watson, Ian Wilson, Malcolm Wright, Roddy Wykes **Cost consultant:** Boyden & Co **Project manager & planning supervisor:** Atkins, Faithful & Gould **Contractors:** Sir Robert McAlpine (frame), Laing O'Rourke (façade & fit-out), O'Rourke Civil Engineering (bridge) **Lighting design (retail fit-out):** DHA **Catering consultant (retail fit-out):** Grantham Winch Partnership **Illustrations:** 1, 6-8, 11, 13, 15, 17-18, 22: ©Arup/Graham Gaunt; 2, 9-10, 14, 19: Nigel Whale; 3: ©Benoy: 4-5, 12, 16, 20-21: Arup