The Aestheticisation of the Steel Framework: the Contribution of Engineering to a Strand of Modern Architecture that Became Known as High Tech

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INTRODUCTION

This paper deals with an aspect of the development of the technology of the steel framework in the second half of the twentieth century. It is specifically concerned with its development in the context of the High Tech style. This style was a strand of Modern architecture that evolved in the second half of the twentieth century. It was developed in the work of some of the most prominent architects of the period including Norman Foster, Michael Hopkins, Nicholas Grimshaw and Richard Rogers. It was a style characterised by some of the most prominent buildings of the twentieth century such as the Centre Pompidou in Paris, the headquarters of the Hong Kong and Shanghai Bank in Hong Kong, the Lloyds Headquarters building in London and the International Rail Terminal at Waterloo Station, also in London. In many of the High Tech buildings the architectural effect was dependent on exposed structural steelwork. It was in connection with such usage that the aestheticisation of the steel framework occurred.

A BRIEF OUTLINE OF THE BACKGROUND TO HIGH TECH

Although it was not unique to the UK, High Tech architecture was particularly strong in Britain, possibly for historical reasons. As Colin Davis pointed out in his book *High Tech* (see bibliography), it had its roots in the British Arts and Crafts Movement, with which it shared a concern to celebrate good, honest construction in the service of a functional building. The underlying ideas were not, however, exclusive to Britain. Architect/engineers such as August Perret, Robert Maillart, Pier Luigi Nervi and Eduardo Torroja, who all produced significant Modern buildings, worked along similar lines.

What High Tech shared with the work of these early Modern practitioners was a desire to include the structural armature of a building in the architectural statement. In the case of individuals such as Nervi and Torroja, the expression of the structural makeup of a building was all that they believed to be necessary to create architecture (This is clearly demonstrated by their writings: see bibliography). It is significant, however, that neither Nervi nor Torroja (nor indeed Perret or Maillart) had been trained as architects. This did not prevent them from being accepted into the world of architecture in the early Modern period, such was the pre-occupation of architects at that time with ideas of function and the elimination of ornament, but it does distinguish their works from those of the practitioners of High Tech.

High Tech, which was a phenomenon of the second half of the twentieth century, involved a combination of a set of ideas of diverse provenance [see Davies]. What primarily distinguished it from the work of architect/engineers such as Maillart, Nervi, Perret and Torroja was that it was created by architects and engineers working together in design teams. The image-making and use of symbolism, on which architecture depends, was combined in High Tech with the utilitarian approach of the engineer. In its British form, High Tech was originated by a small group of individuals who coincided in London in the late 1960s. They evolved an architectural vocabulary that gave symbolic meaning to the structural elements of buildings. This required that serious attention be given to the visual qualities of structures.

Prior to High Tech, the steel frameworks that supported buildings had been encased in fire-proofing material which concealed them from view. They were ungainly affairs and the joints between the various elements, with their rivets and gusset plates, were particularly unpleasing aesthetically **(fig 1)**. This was the challenge faced by the architects and engineers of High Tech – a challenge to which they responded by beginning to work together in new ways. In the context of High Tech, a new working relationship developed between the various contributors to the design of buildings and architects found themselves working closely in design teams with structural engineers. This required a shift in attitudes and perception: on the one hand, architects had to regard engineers as individuals who could participate in the design process and who were not mere technicians; on the other, engineers had to begin to take a serious interest in the visual aspects of structure. Both of these happened in High Tech.

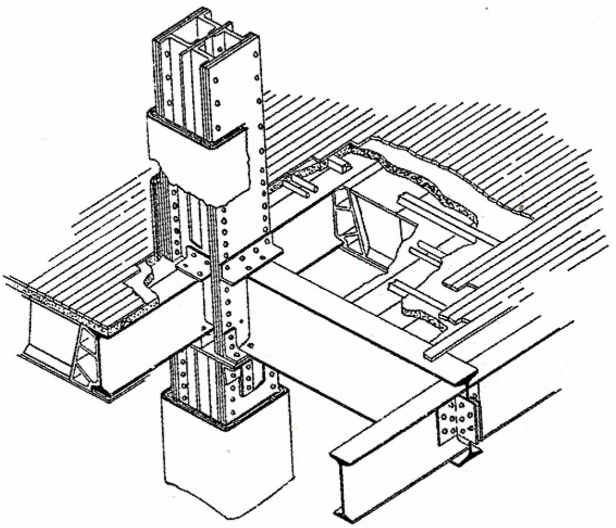


Figure 1. Detail of connection for an early steel framework by William Le Barron Jenny.
The appearance is clumsy but the structure will be completely hidden in the finished building.

Another challenge for the inventors of High Tech was that new techniques for fabricating steelwork, particularly the joints in steelwork, had to be developed, because it was the joints that tended to make conventional steelwork ugly and utilitarian in appearance. The evolution of jointing details that were aesthetically pleasing required that techniques that were new to building, such as site welding, be adopted, and that new materials, such as weldable cast steel, be embraced.

CHANGING PROFESSIONAL RELATIONSHIPS IN THE EARLY MODERN PERIOD

The introduction of the technology of steelwork (and also reinforced concrete) to architecture brought about changes in the relationship between architects and their technical collaborators and broke a pattern that had been established since the time of the Renaissance in Italy. At that time architects had emerged as the designers only of buildings. A separate group of builders, people who were concerned with the construction only of a building, also emerged. These builders were thoroughly familiar with the technologies of masonry and timber and could be relied upon to build a sound building in these materials. It was a pattern of relationships that existed until the Modern period.

The new technology of structural steelwork was one that neither the architects nor the conventional builders understood. It was a technology that had been imported into architecture from civil engineering, where a different relationship existed between the designers and builders of structures. This was the world of consulting engineers, who were the designers of structures, and contractors, who were the equivalent of builders. With the introduction of steel and reinforced concrete frameworks into architecture the two worlds of architects and builders, on the one hand, and consulting engineers and contractors, on the other, were forced to realign themselves.

One of the most fascinating aspects of the study of the architecture of any age is its relationship with the technology on which it depends. In the Modern period the juxtaposition between art and technology was particularly problematic due to the aspiration of most Modern architects to celebrate technology. In most cases this was done purely symbolically, for example in the work of Mies van der Rohe. With High Tech it became literal as well as symbolic because, in High Tech, the structural armature of the building became a significant, often dominant, part of the architectural vocabulary. This required that architects and engineers developed the visual aspects of buildings in close partnership.

The origins of this in British architecture can be traced to the 1920s and 30s where a small number of engineers who were sympathetic to the agendas being pursued by the architects who were creating the new Modern architecture were practising. The most prominent of these were Ove Arup, Felix Samuely and Owen Williams. Each made a unique contribution to the development of Modern architecture in the UK. [Williams, who operated as an architect/engineer, was not so important in the subsequent development of High Tech and will not be considered further here.]

Arup and Samuely were the precursors of the engineers who were involved with High Tech. They worked in close collaboration with architects in ways which resulted in the architectural and structural engineering aspects of buildings being evolved together from the beginning of a design. Perhaps the most significant building to result from this in the early Modern period was Highpoint 1, by Lubetkin and Arup. Unlike most of the rectilinear, white-walled buildings of the period, the architecture and engineering at Highpoint were completely complementary due to the working method adopted by its designers. This 'design-team' approach would be critical to the evolution of High Tech.

It is significant that the two leading engineers of High Tech (Tony Hunt and Peter Rice) had connections with Arup and Samuely, and through Samuely also with Arup. [Samuely had worked as an assistant to Arup in the 1930s, most notably on the design of the Penguin Pool at London Zoo with Bertold Lubetkin.] Arup therefore stands at the head of this pyramid of engineering talent.

Hunt, who collaborated with Norman Foster, Michael Hopkins and Richard Rogers (the founders of British High Tech) in all of their early buildings, spent his formative years as an engineer (1951 to 59) in the office of Samuely and freely acknowledges his debt to both Samuely and to Samuely's partner Frank Newby. Rice, who began his engineering career working on the Sydney Opera House and who was chief structural designer on the Centre Pompidou in Paris and the Lloyds Headquarters Building in London, spent his entire professional career in the employment of Arup. Both of these engineers, who were so essential to the emergence of High Tech, owed a great deal to the working methods that had been pioneered by Arup and Samuely in the 1930s.

THE AESTHETICISATION OF THE STEEL FRAME

The primary theme of this paper is the aestheticisation of the steel framework in the context of the evolution of the High Tech style. This involved both the development of new relationships between architects and engineers and the adoption of new technologies. The version of High Tech that occurred in the UK was unique and also, in the period between 1965 and 1992, contributed significantly to the critical discourse on Modern architecture. The architects who initiated the movement in Britain were Foster and Rogers, working with Hunt as engineer.

These individuals were, of course, not operating in a vacuum. There had been precursors. In the case of exposed metal structure the examples of Behrens' AEG Turbine Factory in Berlin (1909), the Hunstanton School in England (1954) by A and P Smithson and the Farnsworth House (1950) by Ludvig Mies van der Rohe have to be acknowledged. The movement started by Foster, Hunt and Rogers took this approach to a different level of importance and involved an amalgam of aesthetics and technologies that could perhaps be compared with that which had occurred in the days of the master builders who built the Gothic cathedrals. The architects of the earlier twentieth century buildings had been concerned with the honest expression of structure. What was different about High Tech was that it aspired to make structures that were beautiful.

British High Tech began with a small building in Swindon, that has since been demolished – a factory for the Reliance Controls company which was completed in 1967 **(fig 2)**. The architects were Team 4, a practice founded by Foster and Rogers, and the engineer was Hunt, who by this time had left Samuely and set up his own practice.

Figure 2. The Reliance Controls factory, Swindon, England, 1967. Team 4, architects; Anthony Hunt Associates, engineers. This was the first building of British High Tech.

It is worth digressing at this point to consider Hunt. The contribution of Hunt to the rise and success of High Tech has not been adequately recognised. It is arguable that Foster and Rogers could not have achieved their success without Hunt and there is no doubt that, in their early years in practice, they benefited greatly from his abilities.

In addition to being a highly innovative and imaginative engineer, Hunt was greatly interested in all aspects of visual design. As with most people who have a serious interest in the visual, he is a superb draftsman, and his free-hand sketches of engineering structures, that range from conceptual drawings for large scale projects to sketch details for junctions and connections, such as those that he made for the Reliance controls building **(fig 3)** are testament to this. Many of the latter were so good that they were able to function as working drawings as well as being beautiful in their own right.

The Reliance Controls factory represented something that was completely new in British industrial architecture. The respects in which it was original are too numerous to discuss in this short paper.

From a construction history viewpoint they are concerned with the aestheticisation of the steel framework and its cladding and it is this aspect only that will be considered here.

The Reliance Controls design was basically a single-envelope enclosure. With this building, Foster, Rogers and Hunt explored the idea of making a building from industrially-produced components that were simply assembled on site. Tony Hunt, in particular, liked the idea of a building that was a 'kit of parts', with as few types of part as possible.

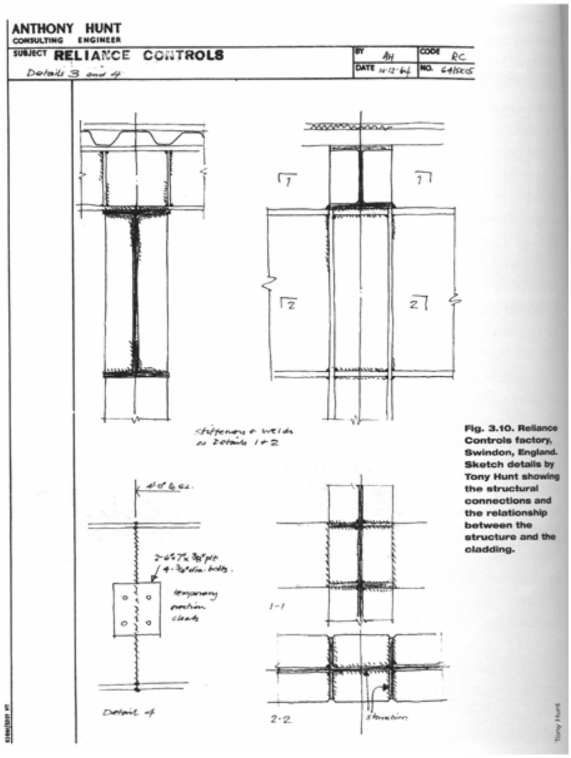
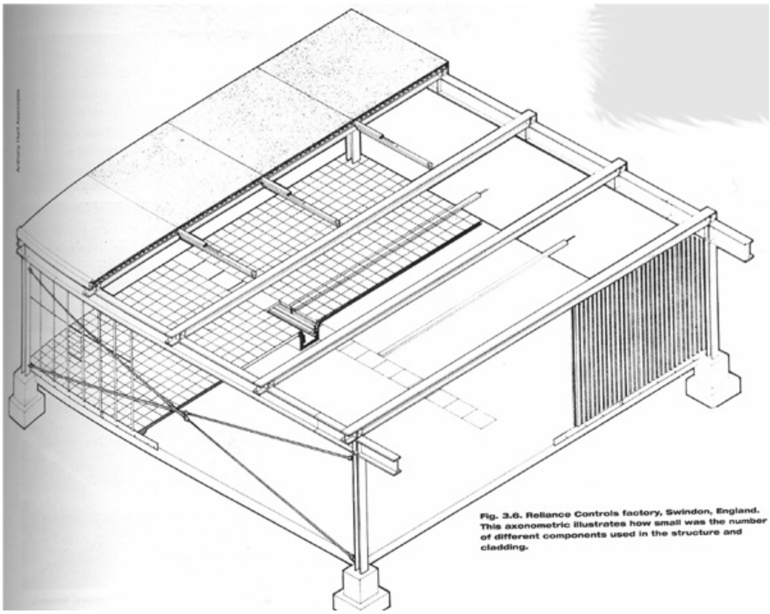


Fig. 3.10. Reliance Controls factory, Swindon, England. Sketch details by Tony Hunt showing the structural connections and the relationship between the structure and the cladding.

Figure 3. Sketch detail by Tony Hunt for the Reliance Controls factory. These elegant free-hand drawings also served as working drawings.

At Reliance Controls the minimisation of component types was achieved to a remarkable degree with the structure, which was reduced by Hunt to one type of column, two types of beam and a bracing element **(fig 4)**. The elimination of the need for cladding rails, through the development of a wall-panel system that was capable of spanning from the floor slab to the roof structure, contributed to this minimisation. The elimination of bracing elements in the roof plane was also significant and was made possible by the use of the profiled metal roof deck as horizontal-plane diaphragm bracing. Tony Hunt recalls that this was achieved by providing many more fastening elements between the roof deck and the structure than would normally have been required, but admits that the ability of the roof to act as a diaphragm in response to wind loading was untested: “These were the days when things could be done by the seat of the pants. We would not get away with this kind of thing today.” In other words, the system did not comply with received wisdom, as documented in building standards, but was judged by its designer, correctly, to be satisfactory.



Anthony Hunt Associates

Fig. 3.6. Reliance Controls factory, Swindon, England. This axonometric illustrates how small was the number of different components used in the structure and cladding.

Figure 4. Structural and cladding elements of the Reliance Controls factory. The elegance of the design is due in part to the minimal number of components involved.

The high level of simplicity in the structure and cladding was crucial to the aesthetics of the Reliance Controls building. So also was the placing of the perimeter structure outside the building's envelope. The visual justification for this was that it allowed “... a visual statement to be made of what the structure was.” [Tony Hunt in interview with the author.] The highly mannered visual treatment of the structure (exposure, projection of beams beyond perimeter columns, redundant cross-bracing) was in fact crucial to the design strategy. This, together with the fact that the building was made from readily available industrially-made components, which were combined in a seemingly effortless way to produce a coherent and elegant aesthetic, was what gave the building its visual quality. These attributes ensured that the Reliance Controls building became a pioneering work that would influence industrial architecture for the next three decades.

Perhaps the most significant innovations at Reliance controls, so far as construction history is concerned, were the use of the design-team approach and of site welding **(fig 5)**. The design of the building evolved in a genuine team effort in which Hunt participated fully in all of the significant architectural decisions. This established a pattern of working that was critical for High Tech.

Figure 5. Site welding, that was rare at the time, was exploited by Hunt from the very beginning of High Tech.

The use of site welding was crucial to the production of a framework that had the required aesthetic quality because it was the only means by which the very elegant and uncluttered joints in the Reliance Controls frame could have been achieved.

By the 1960s, welding was an established practice in structural engineering for architecture. It was, however, regarded as a technique that could only be reliably performed in the controlled conditions of a workshop. Steel structures were therefore detailed to be prefabricated by welding into components that were assembled on site by bolted connections. At Reliance Controls the connections that were made on site were also carried out by welding.

Site welding was a technique that had become, by the 1960s, well established in shipbuilding. Great advances had been made with the welding of steel in the USA in the 1940s in connection with the mass-production of ships for use in the Second World War. The construction industry, with its innate conservatism, was slow to exploit this relatively new aspect of the technology of welding. Something that was demonstrated at Reliance Controls was that site welding was a perfectly viable technology.

It was a technology that was essential to the aestheticisation of the steel framework and it is appropriate here to acknowledge the influence of Hunt's mentor and inspiration, Felix Samuely. Samuely was a pioneer of the use of welding for structural steelwork, having used it at the De la War Pavilion (1935) and also as the structure for Simpson's shop in Piccadilly, London in the late 1930s. Samuely was also obsessed with the idea of minimal structure and his influence at Reliance Controls is evident in the very slender roof purlins **(fig 5)**. Hunt pioneered site welding at Reliance Controls and also had the confidence, thanks to his experience with Samuely, to pear the structure down to an absolute minimum.

He operated similarly with the structure for the Sainsbury Centre for visual arts at Norwich (1978) by Foster Associates. The structure here consisted of a spectacular post-and-beam framework that is exposed in the dramatic end elevations of the building and which makes a significant contribution to the architectural statement. This was also a structure that was heavily dependent on welding. The massive Warren Girder space trusses were prefabricated by welding. This was not, of itself, remarkable. What was remarkable was that the 35m-span main girders were assembled in the fabricating workshop in two halves which were subsequently welded together at their mid points, on site. This required standards of precision, in structural engineering, that were more normally found in mechanical engineering **(fig 6)**.

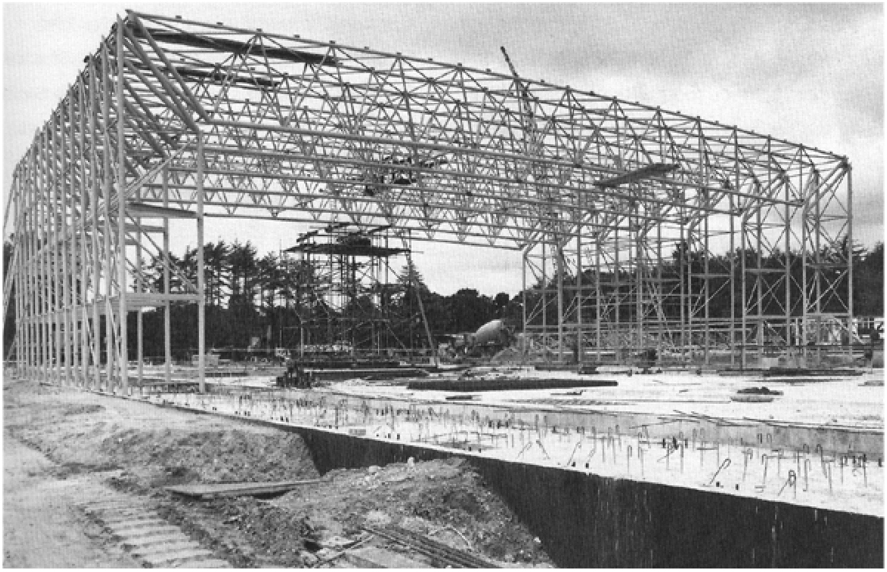


Figure 6. Sainsbury Centre, England, 1978. Foster Associates, architects; Anthony Hunt Associates, engineers. The horizontal space trusses were joined on site at their mid points by welding.

Another steel fabrication technique that played a significant part in the aestheticisation of the steel framework was casting. This had been widely used in the nineteenth century for the manufacture of structural components in the eponymous material cast iron. This was highly successful in the context of frameworks for buildings. It was used less successfully in civil engineering, most particularly for railway bridges, of which failures occurred at fairly regular intervals through the century, culminating in the catastrophic collapse of the Tay Railway Bridge in 1879. The principal problem with cast iron was the difficulty, in the absence of a non-destructive test method, of proving the soundness of castings. The brittleness of the metal also caused problems with cracking at locations of stress concentration. That these phenomena had not caused problems with frameworks for buildings was probably due to the much less onerous loading conditions in comparison to structures for railways.

The Tay Bridge failure led to the discontinuation of casting as a fabricating technique for civil engineering structures. Although it had not caused problems with building structures its use was also discontinued in this field, partly as a consequence of questions about its reliability but mainly because, by the end of the nineteenth century, rolled steel components had become available for structural steelwork.

Casting, as a fabricating technique was absent from the world of structural steelwork for the whole of the first half of the twentieth century. The technique was, however, so useful as a means of shaping steel components that its development continued in other fields, principally mechanical engineering for the production of components for machinery of various types. By the mid twentieth century a technology for producing reliable components in cast steel was well established but, as with welding, this was something that the highly conservative construction industry was slow to recognise.

An early example of the re-introduction of casting to structural steelwork was the connecting nodes of the MERO space frame system that was developed in Germany in the 1940s. This was, however, a mass-produced item subject to the regime of quality control associated with all products of this kind.

The reintroduction of casting to the range of shaping techniques available to the designer of structural steelwork occurred in spectacular fashion in the form of the Gerberette brackets which form prominent features on the exterior of the Centre Pompidou in Paris (1978) [Piano and Rogers architects with the engineer Peter Rice] **(fig 7)**. This was one of the most prominent of the early High Tech buildings. Unlike the nodes of the MERO system the Gerberette brackets were bespoke items, produced in small numbers for a particular building, something for which casting had not been used, in the context of structural engineering for around 100 years.

The production of the Gerberette brackets involved the transfer to the field of structural engineering of a technology that had been well established in mechanical engineering. It can be attributed to the engineer Peter Rice, who on the one hand established that it was a feasible technology and on the other suggested it as a means of reconnecting Modern architecture with craftsmanship and the human hand. The Gerberette brackets were cast in sand moulds whose form was determined from a timber pattern which was hand crafted.

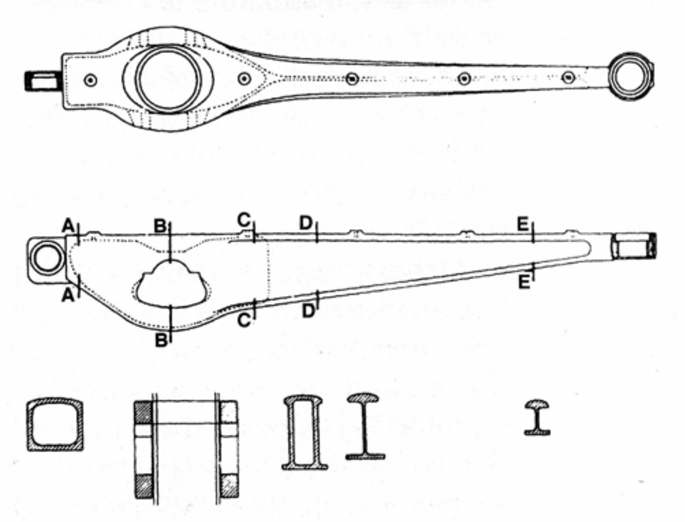


Figure 7. Centre Pompidou, Paris, 1977. Piano and Rogers, architects; Ove Arup and Partners (Peter Rice), engineers. The Gerberette brackets were manufactured from cast steel.

This use of cast steel for a structural framework was not, however, without its problems. To give it the necessary liquidity the steel contained a relatively high proportion of alloying elements. This made it brittle and unsuitable for welding. The Gerberette brackets were therefore joined to the other parts of the structure through pinned connections.

The next development that was adopted by the engineers who brought about the aestheticisation of the steel framework was the adoption of steel that could be welded as well as cast. Weldable cast steel was developed in the 1970s in connection with the offshore oil industry – specifically for use in the junctions between steel elements in the complex geometries of oil platforms. Unlike the technique of site welding and casting, this technology was quickly adopted by the High Tech architects and engineers, possibly because, by the late 1970s and early 1980s, the practise of incorporating new materials and technologies into their architecture was well established by High Tech designers. One of the finest buildings in which this technique was prominently used was the train shed for the International Rail Terminal at Waterloo Station in London (1992) by Nicholas Grimshaw and Tony Hunt **(fig 8)**.

The design of this framework was a truly collaborative effort between the Hunt and Grimshaw offices, in the manner that Hunt had pioneered from the beginning of High Tech. At Waterloo, the architectural and engineering design teams collaborated over all aspects of the building. The

Grimshaw team became very much involved with the design of the structure, particularly with the visual aspects of the complicated connections and the architects and engineers therefore worked together to produce a building that functioned well both visually and technically.

Figure 8. International Rail Terminal, Waterloo Station, London, 1992. Nicolas Grimshaw, architects; YRM Anthony Hunt, engineers.

Due to the awkward geometry of the site, the schemes that were devised for both structure and cladding were very complex. The site had a curvilinear plan which tapered from a width of approximately 50 m at the north ('town') end to approximately 33 m at the south ('country') end. Within this, five railway tracks and their associated platforms, whose layout was dictated by train operating requirements, had to be accommodated. A particular problem was that one of these tracks had to be placed very close to the western boundary of the site. A total height limit of 15 m was imposed because it was intended that an air-rights building would be constructed above part of the roof as a source of revenue to fund the project. [British Rail subsequently abandoned this idea but the decision was taken too late for the design of the train shed to be altered.]

Another technical factor which affected the design of both structure and cladding was the need to accommodate three kinds of predicted movement of the various support structures that underpinned the 400 m long building. Firstly, there were differences in the amount of settlement or heave that would occur in the substrata that underlay the building. Secondly, there was the predicted vertical movement that would occur due to the weights of the trains as they moved in and out. Thirdly, loads caused by the acceleration and deceleration of the trains would cause horizontal movement.

The structure which was designed to accommodate these onerous conditions was simple in principle but complex in detail. The basic structural arrangement was conventional, with primary structural elements spanning across the building and carrying secondary elements to which the cladding was attached. A clear span across the entire width of the building was adopted for the primary structure. This not only created a dramatic space, it also meant that no part of the superstructure obstructed the platforms, whose width was critically small due to the narrowness of the site. In view of the spans involved, an arch form was selected for the primary structural elements and, due to the need for clearance for trains on the track that would run adjacent to the western edge of the building, this was given an asymmetrical profile. A discontinuous 3-hinge arrangement was adopted **(fig 9)** so that the expected movement of the support structures would be accommodated without the introduction of stress into the steelwork.

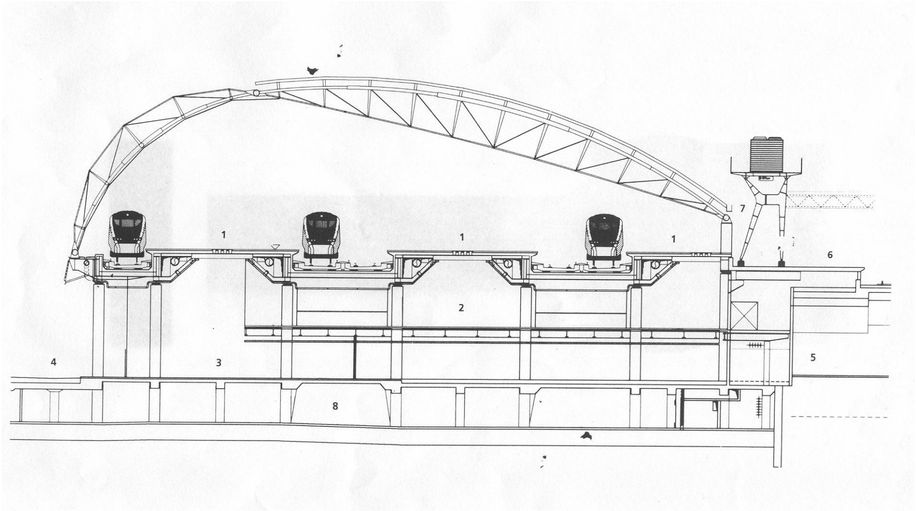


Figure 9. The principal space trusses were arranged as an unsymmetrical 3-hinge arch that could accommodate movement without the introduction stress to the steelwork.

The basic design of the steelwork was therefore fairly straightforward with a logical primary/secondary element arrangement configured to minimise element sizes while at the same time satisfying the various requirements specific to this particular building. For reasons that are not discussed here, due to space limitations, the geometries of the space trusses that formed the primary elements was highly complex **(fig 10).** Great ingenuity and inventiveness were required to realise the design economically on the very difficult curvilinear and tapering site plan, without compromising the architectural opportunities which the scheme afforded. It was in the resolution of this potential conflict that the skill and experience of the Hunt-Grimshaw team was particularly effective.

Figure 10. The space trusses that formed the principal structural elements of the Waterloo Terminal have a highly complex 3-dimensional form.

A significant problem arose in connection with the fabrication of the trusses: that of devising an economical way of coping with the variations in span and height that occurred due to the tapering, curvilinear form of the plan. This required that some form of standardisation be incorporated to prevent the scheme from becoming totally uneconomic. Added to this difficulty was the complexity of the geometry of the primary structural elements. The solution to these problems was the use of weldable cast-steel joint components.

The span of the primary trusses reduces from 48.5 m to 32.7 m in 16 steps and the overall height of the roof and the truss depths and widths were scaled down in proportion to the reduction in span. By keeping some dimensions constant for all trusses (for example, the difference in level between the foundation hinges) and scaling down all others, the geometry at most connections remained constant for all trusses - only the lengths of the sub-elements were different. Variations in the diameters of the sub-elements were limited to two and this meant that only two different patterns were required for each nodal connection. A remarkable degree of standardisation was therefore achieved and this allowed the cost of fabrication to be contained within acceptable limits. It also meant that all trusses were of similar appearance and disguised the fact that changes in the sizes of the trusses occur in steps. The finished building appears to diminish in size continuously with no awkward discontinuities and this is a very important element of its visual quality.

The key to the problem of achieving complex three-dimensional joints that were visually satisfying was the use of weldable cast steel nodes **(figs 11 and 12)**. The very large nodes that were required at the two foundation hinges and at the apex hinge of each arch were refined to a form that was both elegant and expressive of the structural action. The most complex connections occurred on the tension sides of the main trusses where up to five elements and a further three tie-rods, associated with the secondary structure, came together at each node. The use of cast nodes allowed a simplicity of form which would have been impossible with conventional welded and/or bolted connections.

Figure 11. Weldable case steel node for the hinge at the crown of the primary trusses

A further difficulty was presented by the difference in the sizes of the compression and tension sides of the structure. The compression booms of the arches were circular-hollow-section tubes of 355 mm diameter at the mid-span location reducing in size to 219 mm in diameter at the ends. The changes in diameter were accommodated by use of capping plates at the butt joints between the sub-elements. The tension booms were of 75 mm diameter solid rod. In the interest of minimising the sizes of the complicated connections on the tension side of the structure it was necessary to keep the sizes of the elements as small as possible. This meant that the main scantling elements that separated the compressive and tension booms had to be tapered so that they could make satisfactory joints with the large-diameter tubes on the compression side at one end and with small-diameter rods on the tension side at the other. The tapered elements were fashioned by a technique that had been developed previously by YRM Anthony Hunt Associates: trapezoidal plates were bent in a large brake press to form half cones which were welded together to form the conically-shaped tapered scantlings **(fig 13)**. This novel technique for producing tapered elements in hot-rolled steel was a further innovation by the Hunt office in the quest for the ‘beautiful’ steel framework.

Figure 12. The weldable cast steel nodes contributed greatly to the elegance of the final design for the Waterloo Terminal.

Figure 13. The tapered hot rolled scantlings of the principal trusses were fabricated in two halves, by a brake-press technique, which were then welded together.

The final forms of all of the connections in the primary trusses were developed and refined by CAD techniques and in consultation with Nicholas Grimshaw and Partners. The criteria applied were that the forms would perform well from both a structural and an aesthetic viewpoint, these two requirements being accorded equal status.

The Waterloo Terminal was the first major metal and glass railway station to be constructed since the great train sheds of the nineteenth century. Such a building could not have been made earlier than it was. It was dependent upon the technology of computer-aided design and on welding, casting and most especially the use of weldable cast steel. The Waterloo building demonstrates how rapidly the new technologies were being absorbed into building construction by the third decade of High Tech. Reliable casting techniques had been available for most of the twentieth century but it was not until the 1970s that the technique was reintroduced into structural engineering. The technology of weldable cast steel was developed in the 1970s for the offshore oil industry. By the time that Waterloo was designed in the late 1980s it was almost a standard technique for the complex steel frameworks of High Tech.

CONCLUSION

The relationship between architecture and engineering/construction in the Modern period was complex and multi-faceted, and involved changing attitudes to the visual presentation of architectural technology and changing relationships between architects and their technical collaborators. An aspect of this was the aestheticisation of the steel framework. Consideration of this provides insights into the ways in which Modern architecture developed.

High Tech was a significant sub movement of Modernism that flourished in the UK in the last four decades of the twentieth century. It was a style that depended on the use of exposed steel frameworks and that required that serious attention be given to their appearance. This involved the adoption of new technologies such as site welding and the use of casting, and of new materials such as weldable cast steel. It also required that architects and engineers worked together in new types of relationship.

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