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The pre-history of the curtain wall

DAVID YEOMANS

Introduction

Conventionally the history of the curtain wall in texts on architecture goes back to the Crystal Palace, but from a technical point of view there seems little obvious lineage between that building and the cladding of skyscrapers in some form of light-weight walling. What resemblance there is between the Crystal Palace and the glass-clad skyscrapers of today is a rather superficial architectural one; simply the use of a glass wall. Neither the technology nor the form of building have much in common. But perhaps this is a forgivable link to make when the history of the curtain wall is so sketchy and where there is little understanding of either the development of the technologies involved, nor of the various motivations behind the adoption of what might reasonably claim to have become an international vernacular. Most, if not all technologies go through an initial phase of development in which there are competing technical ideas, which eventually resolve themselves into what is recognized as the mainstream of development. The intention of this paper is to trace some of those developments in the inter-war and immediate post-war years in both Europe and America to look at the possibilities that were being explored and the ideas behind them.

An early use of the term simply defined the curtain wall as 'a continuous curtain of masonry penetrated by windows.'¹ This refers to a style of architecture in which there is no overt expression of structure: but here I am dealing particularly with lightweight claddings which are set forward of the plane of the structure and so are uninterrupted by structural elements, whether columns or floors, and are supported by an intermediate structural system. This kind of construction was presaged by Frederick Baumann in 1884 and achieved in practice certainly as early as 1895 in the design of the Reliance Building, Chicago.² The curtain wall that we know today is the kind of innovation that comes from a combination of ideas, the essential elements here being the separation of wall from structure and the subsequent development of lightweight walls.

Curtain walling does not simply mean hanging sheets of glass over the fronts of buildings, even though that was the earliest form it took in Europe. In America, some of the earliest and most successful essays in curtain walling comprised metal panels with windows set in them, and this difference is most clearly exemplified by the two quite different companies that took an interest in curtain walling in Britain and America. In the former, it was the Pilkington Glass Company which encouraged an architectural interest in the smooth glass wall. In America, it was the Alcoa Company which had a strong interest in the development of metal-panel walls, as exemplified by the construction of its own headquarters in Pittsburgh in 1952; and although this building was not constructed until after the Second World War, there were precursors in the inter-war period.

This article, therefore, looks at these two different but related innovations and, although it has not been possible to examine all of the technical issues in detail,³ the intention is to look at the development of the idea as much as the technical development up to 1957, when McCallum described curtain walling as 'the new vernacular'.⁴ For this to be so the idea had

to have been generally accepted and understood by architects. Bowley, who also noted the coincident appearance of glass and aluminium as claddings for major buildings in America, in effect considers the hypothesis that the adoption of glass curtain walling was an innovation caused by the modern movement, technical innovations in glass, and aggressive marketing by Pilkingtons.⁵ When McGrath produced his book on the use of glass, his view of the development of the curtain wall was based upon the well-known architectural pioneers, particularly in Europe in the inter-war period, tracing the line of development, principally from early German examples by Gropius, though the work of Le Corbusier, although he also mentions Polk's Hallidie building, San Francisco.⁶ In his second edition (with Frost)⁷, there is the suggestion that it was Corb's theoretical ideas that led to the curtain walling of the UN Building in New York. Of course, McGrath & Frost were not historians and their review is only intended as an historical grace note to a book dealing with glass in general. However, this view is probably a fair reflection of conventional wisdom on the subject. This article reconsiders these views, placing the glazed curtain wall, as Bowley has done, within the wider context of light-weight wall developments.

Factories

The large glazed wall was hardly a rarity even in the early years of this century. It was a necessity in factory construction, and the development of Albert Kahn's motor-car factories in the United States shows the way in which buildings of this type had increasingly larger areas of uninterrupted glazing.⁸ In Kahn's plant for Pierce at Buffalo, N.Y. in 1906 the concrete structure is a prominent feature of the elevations, but three years later in his Highland Park plant for the Ford company, this had been reduced to a thin grid between large areas of Critall's steel sash, imported from Britain. Even this minimal structure was to disappear from the elevation of later buildings so that in the 1918 Ford Eagle plant the four storey structure was pulled back behind the glazing.

It was in the work of Gropius where glazing was most exploited for architectural effect at that time. The wall of the Fagus factory (Gropius & Meyer, 1911) is still a series of large windows, although windows which extend over the three floors, set as they are in deep frames between the columns. Banham has pointed out, that the windows project forward in the way that they do because the columns between them are battered, effectively reversing the treatment used by Behrens for the AEG Turbine factory, only three years before.⁹ The resulting architectural treatment is that the columns visually support just the projecting entablature of the roof, but unique for the time is the uninterrupted passage of the window frames past the floors, quite natural at the staircase corners, but not for the wall in front of floor slabs.

In the Bauhaus at Dessau (1925-6) Gropius repeats the trick of carrying the glazing continuously over the three floors; but now it is uninterrupted by columns which are also set back behind the glass, and the glass itself is uninterrupted by opaque panels because there is no back up wall. One sees the edges of the floor slabs and the radiators standing on the floors behind. Strictly speaking this was not a factory although, as the workshop block, it had a very similar function, so that this was only a small step away from factory design.

This does not appear to have attracted much attention in the States but a contemporary, which was reported there was the Van Nelle factory, Rotterdam (1925-30) whose continuous glass facade was essentially a simple development of window technology. 1m wide elements spanning 3.7 m from floor to floor were fabricated from 35 mm standard steel Critall sections, manufactured under license in Holland. These were connected with 10 cm

deep steel mullions, which provided structural stiffness. Transoms divided the elements into three equal sections with centre vertical pivot in the centre section of every other one. Insulation was by 'tarfoleum', a tar impregnated peat.¹⁰ Here the elimination of the frame from the elevations was made possible by the use of flat-slab floors and set-back columns.

British factories

Although illustrations of 'daylight factories' had appeared in *Kahncrete Engineering*,¹¹ published in Britain, their architectural expression was still that of the frame with infill panels between the columns, composed of a brick spandrel below a deep window that went right up to the soffit of the floor beam above. The first factory building in Britain to have a completely transparent glass front was Owen Williams's pharmaceutical factory for Boots at Beeston (1930-32). This was a building on the same grand scale as the Van Nelle Factory but, although it had been intended to use a continuous glass wall over the two floors,¹² in the event separate glass walls were interrupted at the intermediate floor by the concrete slab. This floor was turned up to form a kerb at the edge on which steel window frames sat, the glass held into these frames using aluminium glazing beads. The thickness of the slab showing was reduced by chamfering the underside, but it is the kerb that is seen, emphasising the horizontal effect of the building. This result was impressive enough to be noticed by at least one continental journal.¹³

Ellis & Clarke's Daily Express building in Fleet Street (1929-33), with Owen Williams as structural engineer, had a completely glass wall, although not transparent. Black was the predominant colour chosen for the cladding which was repeated on the newspaper's other buildings in Manchester (1935-39) and Glasgow (1936-39). The facing glass of the Daily Express buildings was set in lead at the junctions and carried on Birmabright aluminium angles which were supported by steel lugs grouted into the concrete backing. The original intention was to have the facing glass clear of the wall but in the event the gap had to be filled with pumice concrete to meet fire protection requirements (Figs. 1-2).¹⁴



Fig. 1 The Daily Express Building, Fleet Street, 1929-33 (RCHME, Crown Copyright).

Early non-factory examples

Compared with these early European buildings, the first American examples of curtain walling appear surprisingly revolutionary but these pioneering examples seem not to have been followed by other explorers who might have developed this particular architectural territory. The Boley Building, Kansas City, Mo. designed by Louis Curtis (1909) had a glass walls framed by roof parapet and corners. This early experiment was largely ignored by American architects¹⁵ but it was one of several buildings that Dills¹⁶ suggests might have been the inspiration for the better known Hallidie Building, San Francisco (1918), by Willis Jefferson Polk. When the latter building went up, a reporter

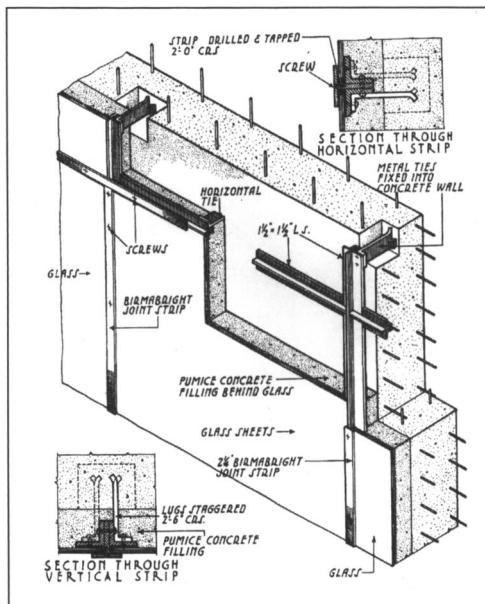


Fig. 2 Fixing glass to a concrete backing with Birmabright coverstrips, the kind of detail used for the Daily Express Building (from *Building*, 1935).

from a local journal seems not to have known of any similar examples since they had presumably gone unreported,¹⁷ but this building was reported in two national journals at the time¹⁸ and so could have had some later influence.

Noted examples of buildings in Europe in which the wall was treated as a glazed screen are the Maison du Peuple, Brussels, by Horta, (1896-9), and the Samaritaine Department Store, Paris, by Frantz Jourdain, (1905).¹⁹ However, across the river from the latter was another department store in the Rue de Rennes which was noticed by *Construction Moderne* at the time.²⁰ Designed by Gutton, this had an exposed frame with the glazing set between the columns and continuous over the first and second floors. The article notes that : “*En effet la façade devait être une grande vitrine*”. While precedents for these few examples are difficult to trace, and their

influence on others seems to have been minimal, coming together as they do, they nevertheless give the impression that there was something in the air; an idea that a number of architects wanted to explore. That Polk was in Paris at the turn of the century, and was later known to be a friend of Curtis, suggests that both early American and European essays in glazed walls should be seen as part of the same movement.

The *Architectural Record* attributed the design of the Hallidie Building to an “urgent demand for light”, noting three novel features; 100% glass rather than the 25-50% which was common at the time; the glass being on the street front; and the use of columns set back from the facade. Dills, reproducing two drawings and a photograph of the building under construction, considers possible precedents, illustrating a number that have large areas of glass. None of these was a European example and it seems unlikely that we can consider the development of architectural ideas in the US as settled.

Nothing like this was seen in Europe until the building of the Bata shoe store in Prague (1927-9) designed by Ludvik Kysels, although this still did not have a full glass facade. It followed his Lindt Department Store by two years, a narrow building in Wenceslas Square with large areas of glass. In the Bata store “the ribbon windows overlooking Jungmann Square almost swallow their ledges so that all that remains are the shining white strips between them.”²¹ The architect was seeking the maximum area of glazing but, unable to completely dispense with the supporting floor, chose to express it clearly: the Parisian examples of twenty years earlier were not followed. One might imagine the store to be a building type that could have made good use of large areas of glazing, particularly in the inter-war years before the development of fluorescent lighting.²² Nevertheless, this was not how shop design developed and other architects did not take up this lead and when curtain-walled shop fronts did appear they were rarities. Even in Prague a decade was to pass before the White Swan department store was built which did have a curtain wall.²⁰

Theoretical ideas

It is in the nature of architecture that the appearance of a new kind of built form or new building material will be accompanied by theoretical explorations of its possibilities. In this way the 1920s saw the production of a number of books and projects exploring the use of glass: their subject was glass rather than the curtain wall because the latter was at that stage only one possible manifestation of the material. Also, it was only architectural forms that were being explored rather than any associated technology that might enable the ideas to be translated into reality. The beginning of this was Scheerbart's 1914 book,²⁴ later commented on by Banham,²⁵ but the best known explorations of the architectural possibilities of the glass wall were those of Mies van der Rohe, beginning with his glass tower in 1920. These projects were later described by Korn in a book that clearly set out some of the ideas of the curtain wall. *'Never before did man succeed in enclosing and dividing up space by a single membrane . . . but only with certain qualities of a solid wall, such as defence against temperature variation and noise. . .'* *'There is evidence of a new structural concept where all load-bearing elements are kept within the core of the building, leaving the outside wall free to be nothing but a wrapping to enclose and allow light to penetrate.'*²⁶

His illustrations begin with the glass skyscraper model by Mies of 1920-21 but include other projects for Berlin, Stuttgart, Moscow and Chicago encompassing factories, offices and department stores. He shows Le Corbusier and Jeanneret's Centrosoyus Building Moscow (1928). By the time this book was published the completed buildings he was able to show included the Dessau Bauhaus (1925-6) and the Van Nelle Factory (1928-30) but it was too early to illustrate Corb's Cité de Refuge in Paris (1933).

These ideas were all very positive but when John Gloag commented on the idea of the transparent wall in 1935 he did not view the prospect with unalloyed delight.²⁷ The starting point for his article was Frank Lloyd Wright's St. Mark's Tower Project rather than any of these European examples. While he was happy to see transparent walls for factories and offices, he looked with dismay upon the prospect that they might be used in apartment buildings, partly because of the loss of privacy involved and partly because he could see the difficulties of providing sufficient insulation in cold climates. He was unable to bring himself to condemn Frank Lloyd Wright's idea, but this article was a condemnation of certain, unnamed, young modernists.

Steps towards the curtain wall

By this time glass architecture had progressed well beyond the ideas stage because in the same year Warland produced an article demonstrating how to use glass as a cladding material.²⁸ Warland was a prolific writer on construction at the time, dealing particularly with masonry walls, and the use of glass as a cladding was a development that he would have needed to address. At the same time the NPL were doing work on the structural properties of glass that would allow architects to design large windows with confidence.²⁹ The clear architectural agenda behind the development in Britain that Pilkingtons participated in was the desire for the glass facade. What was wanted was a glass wall, which was by no means the same thing as a curtain wall, and, while Gloag was discussing the transparent wall as a theoretical ideal, Warland's illustrations either showed the use of glass blocks or 'glass walls' in which the glass was simply set as a facing onto a normal structural wall. For the latter, the glass surface was treated hardly any differently from a stone veneer.

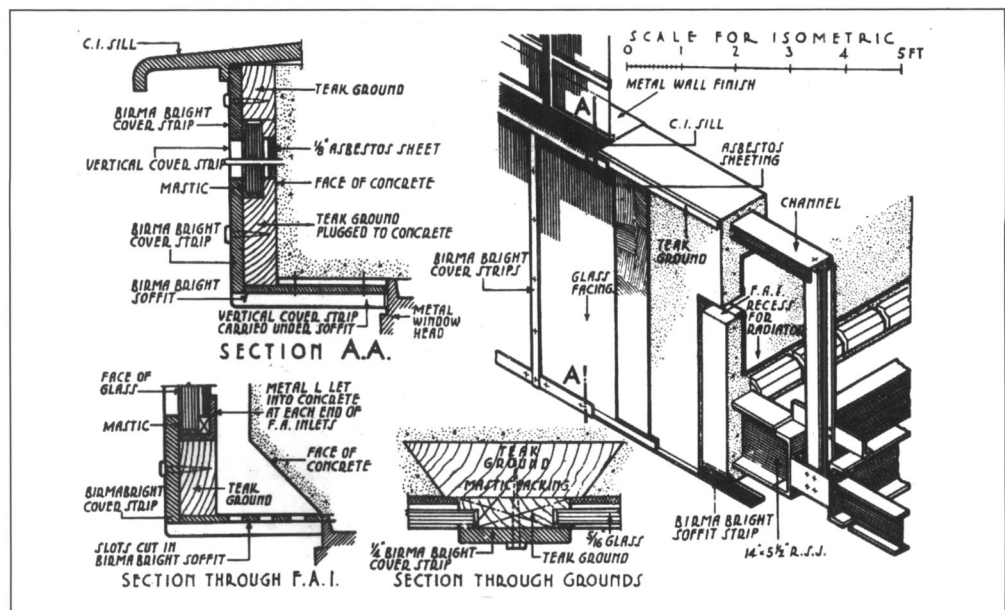


Fig. 3 Details of the glass cladding of Universal House, London, by Joseph Emberton (from *Building*, 1935).

Thus, the Daily Express building can be seen as an example of this exploration of glass rather than of the curtain wall. Another well-known example of the same genre was Joseph Emberton's Universal House (1933) which had bands of 'pale sea green' glass above and below the continuous bands of windows, achieved by the use of set-back columns.³⁰ Cast iron sills were used with the glass facings, again held in place by anodised aluminium cover strips, but here screwed to timber grounds cast into the concrete wall behind (Fig. 3). In 1956 Hope's were to illustrate the cladding of Troy Court Kensington (1935, by Michael Rosenauer) under the heading "The shape of things to come" claiming it to be "a forerunner of curtain walling."³¹ This had pink Vitrolite panels over an otherwise conventional brick wall.

Within this context, Le Corbusier's interest in the use of glass culminated in the glazed wall of his Cité de Refuge, Paris (1932-3). However, this still depended upon support from the floors and so still had a horizontal rather than a vertical direction to the glazing even if this was not overtly expressed. In contrast Peter Jones' store in Sloane Square, London (1935-7) may not have been a true curtain wall but what was significant about it was the strong vertical emphasis that its continuous mullions provided. Thus it has come to be associated with curtain-wall technology, but the curtain wall effect is only an illusion. The windows which form the glazed surfaces actually step forward and back, set in front of the plane of the concrete breast wall and then immediately above it so that the mullions are continuous only in appearance (Fig 4-5). Concrete mullions were used on the first elevation to be clad, but finding construction too slow and their stainless steel facing too expensive, a change was made to prefabricated pressed steel mullions with a bronze facing. Between the windows, the mullions comprise three, 14-gauge mild steel pressed sections fastened together to which the bronze facing was attached. At each floor there is a concrete breast wall up to sill level, and the plane of the curtain steps out to clear this. Thus, the structure of the mullions is interrupted by the main structure of the building and only the bronze facing is continuous. As the wall is 60 ft (18 m.) high this continuity was achieved by sleeving the bronze section at 15 ft (4.5 m.) intervals.³²



Fig. 4 Peter Jones, Sloane Square, by William Crabtree with Slater Moberly and C. H. Reilly as consultants, 1936-8 (from *Architectural Review*, June 1939).

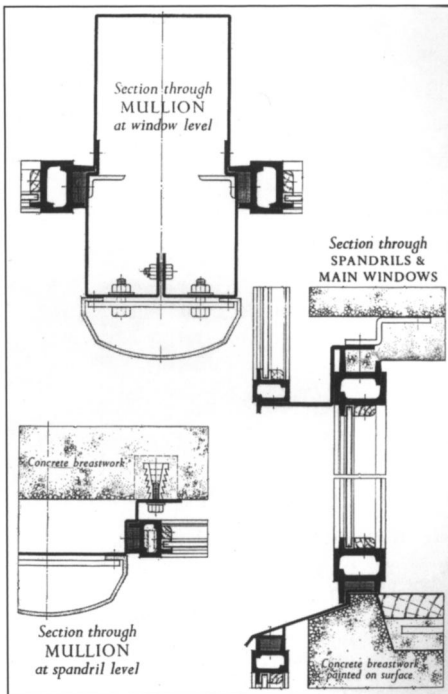


Fig. 5 Peter Jones: plan section of mullions at both window and backing wall level, together with vertical section (from Henry Hope and Sons Ltd., *Hope's Window Walls*, 1956).

The dependence on window technology was such that the concrete spandrels under the windows were simply painted and set behind opening casements "to allow for repainting the concrete"³³ although this looks like expediency turned into a virtue by the suppliers, Hope Windows. At this distance in time we can only speculate about the contribution made by Hope's to the final design of this glazed wall and the extent to which this experience encouraged them to develop their curtain wall system after the Second World War.

It was a much smaller but contemporary store that seems to have been the first British use of what we would recognise as a glass curtain wall. TP Marwick & Son's building for St Cuthbert's Co-operative Association in Edinburgh (1937) had a complete glass window-wall. The shop was built on a very narrow site and it was claimed that the glass was to provide maximum light.³⁴ The glazing was carried in front of the structure on small cantilevers from the floor slab and there was therefore no fire-stopping between the glass and the floors. Such a detail immediately

raises the question of regulations, since the requirement for fire stopping had affected details elsewhere. Of course, the position in Britain was confused at the time with a multiplicity of regulations, but a simple sample demonstrates both this diversity and how a glazed wall was possible in this case. Just before the outbreak of the Second World War, bylaws for the London Borough of Hendon required external walls to have a one-hour fire resistance. This was probably typical of many other English authorities, but Edinburgh bylaws at the time made no stipulation whatever about the fire resistant properties of the external wall.

One oddity stands out. Finsbury Health Centre (1935-8), although only a two storey building also has what we would recognize today as a glazed curtain wall, in this case for practical reasons.³⁵ The services run outside the external wall beams and under the window sills which are part of this beam. Therefore some means was needed both to enclose these services and to allow access to them from the outside. To provide this, a timber frame, continuous over the full height of the building, was fixed to the face of these beam flanges. This timber frame in turn carried metal framed glazing, with opaque glazing used in front of the service duct, which was removable so giving access to the services.

Commercial interests

In the inter-war period the curtain wall was an aesthetic ideal appearing before the development of the technological device which we now recognize. Architects may have been aiming for continuous glazing, a continuous glass surface or may, as in the case of the Peter Jones' store, have used the mullions as an ordering device. While the adoption of such an aesthetic may have been desirable for the prestige projects referred to, technically it had little to commend it for more commercial architecture. In all cases the assembly of the external wall was very much a piecemeal affair, ill-suited to rapid, trouble-free construction, and the Peter Jones' episode shows that even for prestige projects the construction could prove problematic.

It was this architectural interest in the use of glass walls that was taken up by Pilkingtons who, having acquired Vitrolite Construction Company (Europe) Ltd. in 1932, reforming it as British Vitrolite,³⁶ set out to market the product through a practical demonstration of its use. This they did partly through an hotel building at Kirk Sandall near their Doncaster works. Designed by T. H. Johnson, a local architect, and with interiors by their own architectural department, the Kirk Sandall Hotel was opened in 1934.³⁷ The entire external surface of this building was clad in shell-pink Vitrolite above a black base. The panels were 5/16 inch (8mm) thick and about 3 ft (900mm) square.

Also in 1932 Pilkingtons began to display their products at the Building Exhibition at Olympia, although it was not until 1936 that they used the stand itself as a demonstration of the architectural possibilities of glass.³⁸ Until then only window and glass-block manufacturers had stands at the exhibition.

In 1938 the firm's ambitions and the scope of their marketing ideas were displayed in a sketch by Furneaux Jordan for the complete replanning of Princes Street, Edinburgh,³⁹ designed to make the maximum use of glass in the new buildings which were being proposed. It seems that Pilkingtons had formed a group of architects into the 'Glass Age Town Planning Committee' by whom a number of city areas "have been or are being redesigned in glass."⁴⁰ It is not possible to see much detail in the published drawing but there was a strong horizontal emphasis to most of the buildings which suggests that curtain walling was not the intention; nor was the kind of surface treatment seen at Kirk Sandall. These were buildings in which the floors were clearly expressed. Only in one building, the

closest to the supposed observer in the perspective, do we see the vertical treatment that may have been indicative of curtain walling.

Pilkingtons were certainly interested in promoting the use of glass, as Bowley has noted, but they were hardly proactive in the field. Architects had already demonstrated the ways in which glass could be used and it was only after a number of British architects had shown an interest in its use that Pilkingtons acquired the Vitrolite company.⁴¹ In 1938 the journal *Glass* published a review of the MARS exhibition, because it saw that the frame buildings proposed by these architects might imply glass walls. For the first time that year, it reported on the Building Exhibition,⁴⁰ which it said would show the latest applications of glass as a structural material and, on a more prosaic level, it reported a test carried out to demonstrate that a glass block wall provided a one hour fire resistance.⁴³ Pilkingtons' contribution to all of this was that they then employed their own design staff to demonstrate the possibilities of glass in building. However, given the lateness of the hour, it is difficult to imagine that these efforts had much effect on architectural ideas before the outbreak of the War.

American developments

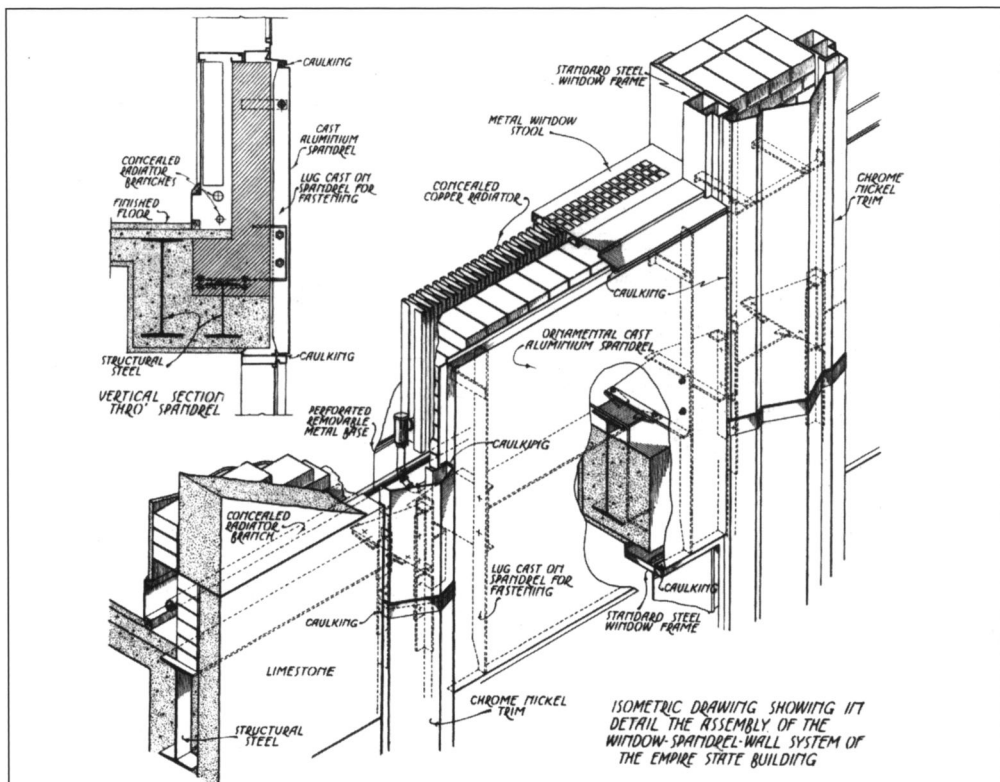


Fig. 6 Wall details of the Empire State Building, New York (from *Engineering News Record*, 1931).

This was all quite different from the approach in the US where there were clear practical reasons behind the development of curtain walling, as much as an architectural agenda, and where there was a search for a new technology that would enable these advantages to be realized. This is made clear in one of the articles in a special issue of *Engineering News Record* in February 1931 in which H.R. Dowsell discussed the need to move to lighter

external walls.⁴⁴ He regarded the use of masonry walls in tall buildings as an ‘illogical heirloom’. Even when cast-iron panels were used, they were backed up with masonry. The idea was so deep rooted that practically all building codes required masonry walls which were still graduated from top to bottom, even though supported at each floor. However, reducing the thickness of masonry walls led to leakages and so attention was directed to waterproofing, rather than to developing a new technology, the task being to make the design independent of the standard of workmanship in the masonry because cost cutting had resulted in poor standards of waterproofing application.⁴⁵

Dowswell referred to the new New York City code which left the way open for other forms of enclosure that met required standards of fire and weather resistance. The Empire State Building had cast-aluminium panels forming the spandrels between the windows, between which was continuous vertical chrome-nickel trim (Fig. 6). Dowswell suggested that this design pointed the way forward, noting the advantage of lack of corrosion of aluminium compared with cast iron. He provided technical details of the cladding of the building, particularly commenting on the advantage of rapid construction. The significance of this article is its concern for the technical problems associated with tall buildings and the need to solve them. An external cladding offered a solution quite independently of any aesthetic merit or any architectural agenda that there might be.

Davison

Robert Davison was an early champion of the idea of curtain walling, although not involved initially in its design. In 1929, he was a member of the editorial staff of *Architectural Record* and produced an extensive article on new construction methods which included a section on curtain walls. In this he remarked that, “*it is the opinion of some leading architects of Europe and America that it is entirely practical to eliminate masonry by using metal mullions, as in the Bauhaus. Or, if one desires to have solid walls for architectural effect, one may use metal panels between the mullions.*”⁴⁶ He illustrated the Van Nelle Factory, Rotterdam as an example of the use of curtain walling (his article was followed by a feature article on this same building). However it was not the glass curtain wall that really interested him but rather the metal panel wall. The following year, he was able to report the construction of a block of apartments in Chicago that used a metal panel curtain walling system, but unfortunately few construction details were given.⁴⁷

The advantage of the panel wall to Davison was the increased usable floor area that it gave. Both articles have drawings comparing the curtain wall with a conventional wall, emphasising the additional floor area available when the floor did not have to support the thickness of the spandrel wall under the windows. The Chicago block of apartments achieved even greater usable floor area by using hot air ducts to supply heating rather than radiators. Its metal faced panels were had a 3-inch (75 mm) rockwool insulation and a half-inch (12 mm) plaster backing. There seem to have been no other reports of what appears to have been an innovative building, neither does it seem to have been followed by any other buildings of similar construction.

Its architects were the Bowman Brothers, who were also featured in the Museum of Modern Art’s exhibition of modern architecture. There they presented a project for an apartment block which used a combination of set-back columns with lightweight panels and window frames to form the non load-bearing facade. This had “*only two sizes of window frames (all of aluminum) . . . and the spandrels throughout use large slabs of fireproof insulation material protected on the exterior with a sheet of metal.*”⁴⁸ Again no details were

given but one must be suspicious about the performance of a building which was reported to have only two-inch (50 mm) thick internal partitions. Although Davison may have praised the Lake Front Building because its wall construction provided greater floor area, the impression given by this later project is that the design was being driven largely by an interest in the architects' delight rather than by occupants' commodity.

After 1931 Davison joined the John B. Pierce Foundation to work on the development of prefabricated housing, and did not return to the ideas of curtain walling until the war years. However, there was some possible technical transfer because his housing projects used 'Micorporite' which demonstrated that high levels of insulation could be achieved in thin panels.⁴⁹ He wrote another article for *Architectural Record* in 1946⁵⁰ (by which time he had set up as Robert Davison Associates Housing Research) which, in referring back to his 1929 article and reproducing the same drawings, suggests that there had been little development of the idea in the intervening years. He noted the technical advances made because of war needs, but also the housing needs that it had created, and opined that a more sensible approach to development was to define the material needs and then design products to meet them, rather than to begin with existing materials. He also noted the need for reform of the building codes, with the adoption of performance specifications rather than material descriptions in order to facilitate the development of new materials and forms of construction. Some companies had seen commercial potential in the building industry and Davison noted a number of high-insulation products already available.

In 1947, *Architectural Forum* reported a collaboration between Davison and the architect William Lescaze in the design of curtain walling for a building for the New York Housing Trust.⁵¹ The article contained technical drawings reporting their preliminary studies in which they carried out a systematic analysis of the various types of panel that were possible before settling on a design. The panel illustrated comprised a flat backing sheet with the edges formed on a break press, and spot welded to corrugated sheeting. With sill angles fixed, this then formed a pan to contain the insulation, over which a corrugated outer sheet could be screwed. They also examined the possible sequence of assembly. The system comprised channels, fixed to the face of the reinforced-concrete floor slab with adjustable anchors, and projecting both above and below the slab. These channels did not form a continuous carrier system, just double cantilevers which carried the metal wall panels between the window zones either side. Head and sill members were then fixed to the top and bottom of the panels and windows, or additional solid wall panels, fixed in between. Finally, the channels were covered by an insulated cover strip which was screwed to the panels either side.

The same article included a series of drawings headed with the announcement that *Republic Steel, aware of the curtain wall's potentials, produces an experimental variant which it may ultimately market.*" Although reportedly still experimenting with the system, it was said that the company had no immediate plans to go into production, having no spare capacity to develop this as a commercially available product. The Republic Steel prototype used a different panel design, with a corrugated outer sheet, but the same assembly arrangement. Although manufacture of the panels would have been very simple, here surely was the disadvantage of the system: the appearance provided by the corrugated outer sheet would not have recommended it to architects. It would have had all the utilitarian grace of an American school bus, and this must have limited its commercial potential.

In 1948 Davison described the use of steel panels to form a wall which had been developed in a research project sponsored by the Department of Commerce and which appears to have been a development of the previous work.⁵² The studs of the previous

system had now been replaced with a self contained frame. Instead of vertical studs, two continuous angles were fixed to the structure above and below the floor slab (or spandrel beam) and the panels then fixed to these. The panels themselves were designed with an interlocking joint on all sides. Either steel or aluminium facings were envisaged with “foamglas” insulation. (Fig 7)

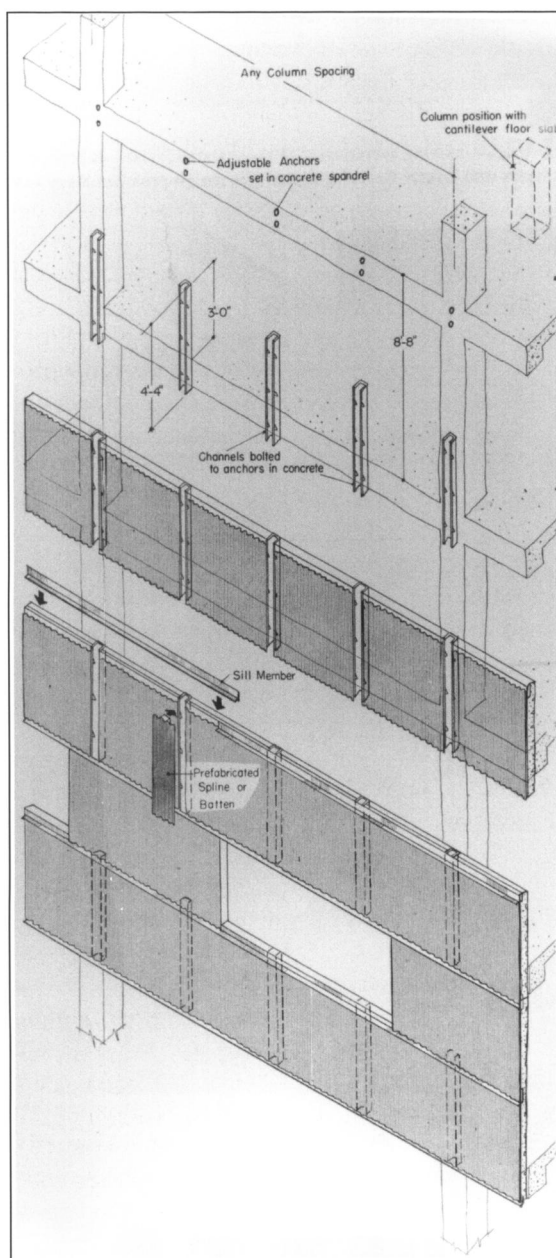


Fig. 7 Fixing panel for curtain walls by Davidson (from *Architectural Forum*, May 1947).

In 1950 Davison discussed the current situation in a contribution to the March issue of *Architectural Forum* which was a special issue on the curtain wall.⁵³ The articles in this issue were preceded by a number of advertisements for curtain-wall systems many of which resembled his panels in being fixed to the face of the structure. Noteworthy are those by Allegheny Metal, illustrating a 4-storey office building and offering a free technical brochure for architects, and USS Stainless Steel which offered both stainless and porcelain-enamelled steel panels and appeared to have an advisory service. It is difficult to know just how commercially well developed these metal curtain walls may have been: Ferro Enamel's advertisement was a simple drawing of a building; Rigidized Metal showed only a full-size mock up of an assembly, while many of the advertisements were for industrial building cladding systems rather than for high-rise buildings.

Davison suggested that development of the curtain wall had, to some extent, been constrained by the requirements of the building codes, which were not exactly logical. The material of an external wall had to be specified so that it would provide protection against the spread of fire from one floor to another. However, although glass could not provide any fire protection, there was nothing to limit the area of glazing and so the obvious approach was to make it all glazing. This is the kind of *reductio ad absurdum* argument that one finds from time to time and which

seldom succeeds in practice, but it is essentially what Owen Williams had done at Beeston and in his later Pioneer Health Centre. The article compared codes in different areas and noted that difficulties with the fire code might be overcome by moving to a performance specification for walls. The commercial advantages of curtain walling were illustrated with a diagram showing that a 6 inch (150 mm) increase in the size of the space as achieved by this reduction in the thickness of external walls. Discussing alternative facing materials and presenting a cost comparison, the article described and illustrated eleven current systems.

Corrugated facings were still proposed by some, but by now Republic Steel's earlier crude profile had become a more elegant shallow V (Fig. 8). Other manufacturers had decided that a flat surface was preferable, favouring panels comprising a number of narrow flanged sheets of stainless steel or aluminium. Only one of these showed clearly how windows were to be incorporated and that was the design by U.S. Plywood based on expressed aluminium box mullions. Also, only one had a reported use and that was by Alcoa for a hospital in Bradford, Pa. designed by Thomas Hendry. The impression given is that most companies at

that time were kite-flying, prepared to respond to enquiries by architects but unwilling to invest in the development of a system until a genuine customer appeared.

The first major panelled curtain walls

It was the Alcoa and the Equitable Life Buildings, that were to realise some of the ideas which Davison had described in his publications, i.e the use of prefabricated panels fixed to the face of the building at the edge of the floor slabs and the omission of a back up wall, although these ideas were not combined in quite the way that he had envisaged. Both these buildings were reported to have been the result of some years of development, but there is no report of their being any trials in smaller buildings and we must assume that these curtain walls were developed specifically for these buildings. The use of aluminium panels was a natural choice for the Alcoa company's own building to demonstrate the possibilities of the material and perhaps establish a new market

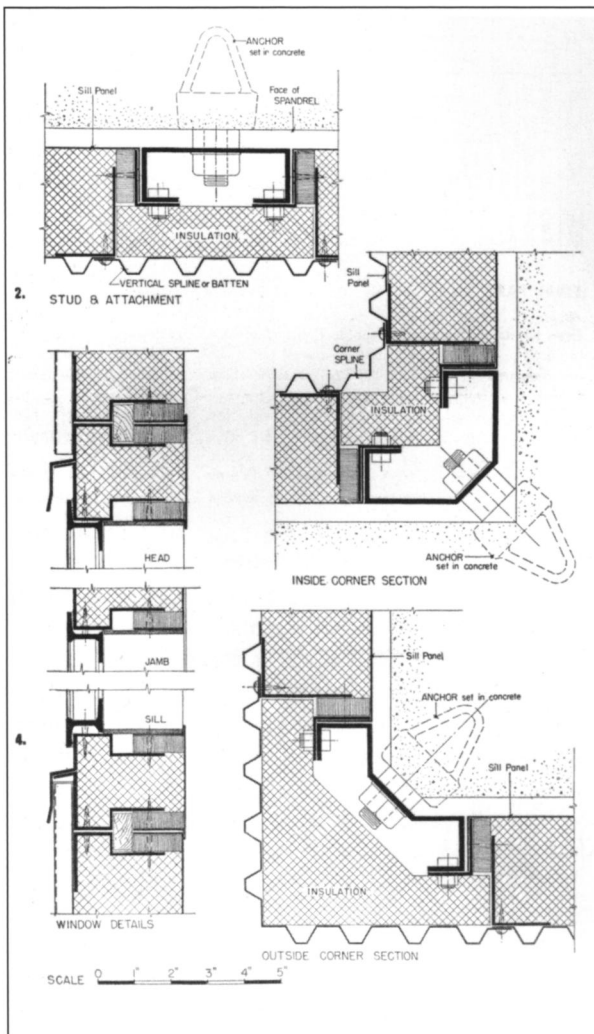


Fig. 8 Metal-faced walls: projected designs by Davidson (from *Architectural Design*, May 1947).

for it. It would have been valuable for them to do this as early ideas and examples of panel walling had either assumed or used steel panels.

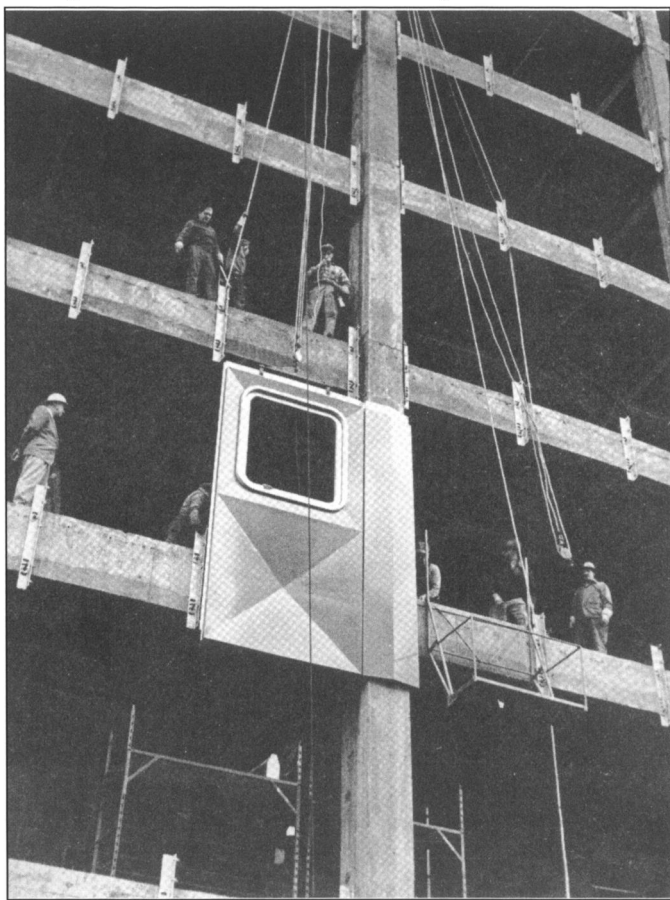


Fig. 9 The Alcoa Building, Pittsburgh, under construction (from *Architectural Record* August 1952).

The Alcoa building has storey-height panels which contain the windows, fixed by 4 inch x 4 inch (100 mm x 100 mm) angles on the face of the concrete, but fastened back with hook bolts to the steel edge beam (Fig 9). These angles project less than one foot (300 mm) above the floor slab and reach down close to the bottom of the panels. Thus, each panel is restrained by these angles at the bottom, but at the top by the panel above which laps over it. Behind the panels is a perlite back-up wall. The vertical joint appears to rely upon its geometry for water exclusion and one wonders what tests were carried out on this.

The panels for Equitable building are much more complex. A porous concrete was first poured onto the backs of the panels to allow condensation to

drain into the weep holes, and then a medium density concrete of 104 lbs/cu ft. (1666 kg/cu.m) was poured over that. This concrete on the back of the panels eliminated the need for a back-up wall, although there were air conditioning units behind them. The site assembly was also more complex with four different pieces, the spandrel panels under the windows, the mullions, which lapped over these, and a broader mullion which covered the columns. Both the mullion sections were in storey-height lengths.

Architectural Forum reported that it took the architects and Alcoa, together with the George A. Fuller Co., several years to develop the system, while the 'master builder' Andrew Eken of Starrett Bros & Eken was said to have been working since 1946 to develop the Equitable's stainless steel panel.⁵⁴ Perhaps so, but these were far more complex in design than the simple panels being suggested in the *Architectural Forum* article of a few years earlier. There was clearly a difference between what might be used for the general run of buildings and what was necessary for these skyscrapers, and the designs for the latter were not the kind of thing that one could imagine being capable of easy adaptation for an extended market.

The post-war glass walls

For architectural interest in the years spanning the Second World War it is essential to look to America where money was available for development and buildings were put up by significant architects using glazed curtain walling. The war demanded aluminium for aircraft production and this provided either opportunities or problems in the post-war years, depending upon how it was viewed. In Britain it affected the choice of material for the production of emergency housing after the war, and it would not be surprising if Alcoa had seen the aluminium panel wall as a means of absorbing production capacity released by the ending of hostilities. However, it appears to have been the foresight of a west-coast architect that resulted in aluminium being used to produce a major glass curtain wall building. In 1943, during the planning stages for the Equitable Savings and Loan Building

in Portland, Oregon (eventually built in 1948), Pietro Belluschi said in *Architectural Forum* that:

*"Our assumptions were affected by the peculiar circumstances found in the Northwest region - cheap power and tremendous expanded production of light metal for war use, which beg utilization after the emergency"*⁵⁵

Belluschi's intention was to use the availability of aluminium extrusions to frame a glass curtain wall. The original idea was also for the building to have aluminium panels but the local building codes required a 4 inch (100 mm) back-up wall. The cladding used both sheet aluminium and extrusions but all carried on steel angles which were fixed back to the concrete. Heat absorbing glass was used in sealed double glazing, and the possible problem of glare was tackled by using a green tinted glass. Curiously, when the building was completed the best technical description of it appeared in the British journal *Architect and Building News* which had detailed drawings of the cladding.⁵⁶

Meanwhile, elsewhere in the States, other architects were using pressed-steel mullions and transoms to provide curtain walling. In 1948 Saarinen, Swanson and Saarinen built a glazed wall over two storeys for a laboratory building at Drake University, with components supplied by the British firm Henry Hope (Fig. 10). A more ambitious project was Anderson and

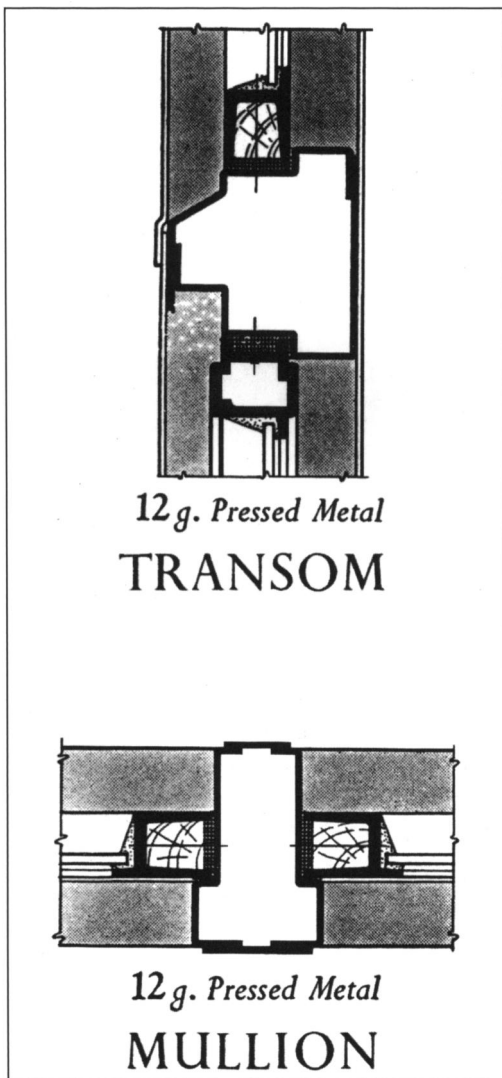


Fig. 10 Transom and mullion of laboratory building at Drake University (from Henry Hope and Sons Ltd, *Hope's Window Walls*, 1956).

Beckwith's Dorrance Laboratory at MIT which in 1950 followed an earlier essay on the same campus into the use of extensive glazing. The wall here was six storeys high and also used components supplied by Hopes. In both cases the mullions were pressed metal rather than the aluminium extrusions used by Belluschi. In the first of these, mullions were formed by pairs of 12-gauge steel pressings held together with flat pieces on the face and back to form box sections, with the windows fixed directly to these. The MIT laboratory was more complex, with 12-gauge sections forming the front and rear of much larger box mullions with lighter gauge sub-frames for the windows - all hot-dip galvanized after assembly (Fig. 11).

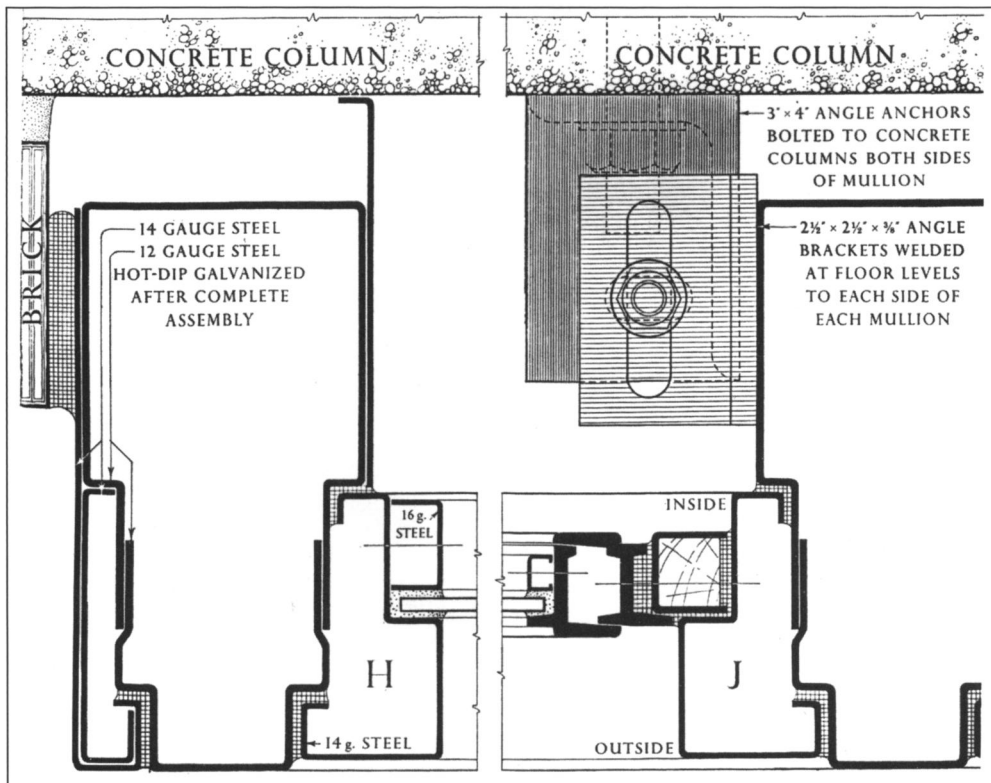


Fig. 11 Mullions at the Dorrance Laboratory, MIT (from Henry Hope and Sons Ltd, Hope's Window Walls, 1956).

In 1952, the same year as the construction of the Alcoa and the Equitable Life buildings in Pittsburgh, New York saw the construction of what must be regarded as the landmark buildings in glass curtain walling, the UN and Lever buildings. These may have presented similar architectural images but they used quite different technologies to achieve their results. The UN building used standard sliding sash windows while the Lever dispensed with opening lights as a means of limiting its air conditioning load. The *Architectural Record* gave the impression that one reason for the selection of this type of architecture for the latter was the clean look that it gave the building, and that it could be maintained; important for the headquarters of a soap manufacturer.⁵⁷ (Fig. 12)

One can understand why developments in Europe should be so different: American architects were coping with a quite different scale of building. The skyscraper presented special problems, unknown in Europe. Given the number of floors, the weight of the wall was a significant element in construction. Speed and ease of assembly were also significant,

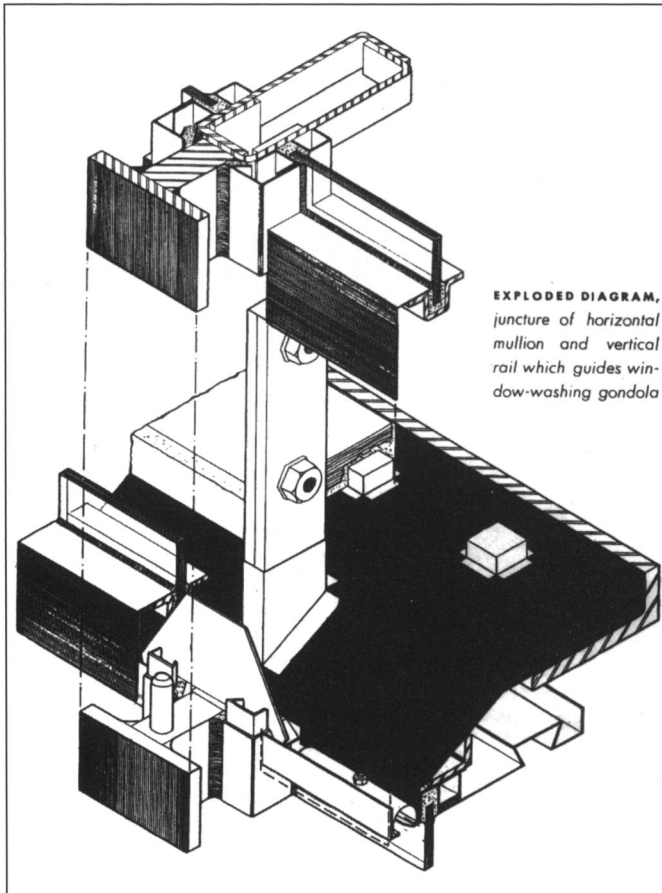


Fig. 12 Cladding details of the Lever Building, New York, using welded mullion section (from *Architectural Record*, 1952).

as might be the loss of rentable space because of thicker walls. Either the lightweight panel wall, hung outside the building, or the glazed curtain wall would have been an advance, but the former must have been attractive because it avoided the problem of fire protection between floors. With the glazed wall, this could only be solved with a back-up wall.

Architects in Europe were not facing the same problems. In London, for example, the 80 foot height restriction remained in force in spite of attempts to break through it.⁵⁸ There had not been the same need to develop a better technology and the only technical advantage provided by a glazed wall was the amount of light that it provided, as seen in the department stores in

Prague. Also in Europe, only the experimental architect Jean Prouvé had shown any interest in metal panel construction, and then as an interest in the development of the material rather than as a solution to a particular problem.⁵⁹ A few years earlier Owen Williams had suggested the possibility of stainless steel being used as a cladding material and Emberton had been designing a building to be clad in sheets of aluminium, but nothing seems to have come of these ideas.⁶⁰

All of the buildings discussed so far were one-offs, the technology in each case developed for the particular building, and they continued to be so as architects explored the aesthetic possibilities of these systems of construction. But if either kind of curtain wall was to develop beyond this and to be used in the commercial sector, it had to be available as an off-the-peg system. The direction that metal-panel curtain walling should take must have seemed far from obvious. There was a wide range of possible panel technologies with different panel materials and surface finishes, different insulating materials and different methods of fixing the panels to the structure. As late as 1955 a research programme at Princeton had been looking at the range of possible configurations of panel and support systems.⁶¹ To have tried to develop and market a system in these circumstances, and with little obvious architectural interest, would have been to have taken a considerable risk. In these respects, the glazed curtain wall had advantages. There was a history of architectural

interest in glazed walls and the curtain wall could be developed easily from window technology and could be produced more easily in a range of sizes to suit the dimensions of any building. Moreover, that the carrier and the infill panels were separate facilitated a range of elevational treatments. It was a cheap form of walling and could be easily erected which meant that it was suitable for repetitive work and for buildings where economy was the driving consideration.

The first building programme in the United States to recognize this came in the early 1950s when the firm of Sherlock, Smith & Adams designed a number of hospitals for the Miners Memorial Association in West Virginia. In all ten hospitals were built and this was sufficient for a team of designers to be set up by the Truscon company to collaborate in designing a curtain wall system to be used on all of the buildings. This eventually became a standard system of the company. Reportedly, it was the contractor who suggested that as much as possible of the buildings should be prefabricated and, following a search by the architects, Truscon accepted the risk of working on the design of a walling system.⁶² These were low-rise buildings and what was wanted was a mullion system capable of carrying both sunshades and a porcelain steel panel with good insulation properties. Eventually, using 1 inch (25 mm) of glass fibre and a small air gap between the inside and outside metal faces, Truscon designed a panel only 1 1/2 inches thick to be incorporated into their frames.⁶³ Like the British firm Hope Windows, Truscon were probably a natural manufacturer for this kind of project. Their background was (at least since the early 1920s) in the manufacture of standard prefabricated buildings and they were marketing a range of building components including windows.⁶⁴ They would have had the technical experience and the incentive to invest in the expectation of being involved in the construction of so many hospitals.⁶⁵

In Britain there was a similar concern to find a simple economic form of walling. In 1943, Godfrey Mitchell of Wimpey had foreseen the necessity of this when he wrote to a colleague:

"I think we have got to make up our mind for the next ten years we are going to have no building in this country except Utility Building . . . owing to the high cost of building and the immense call on the industry, anybody who has got to put up a big shop, block of offices, flats, cinema, or anything of that sort, will have to get down to the barest essentials of a steel-framed building with the minimum of brickwork cladding. This austerity building will probably develop a new style of architecture where proportion, balance, suitability for purpose, are the dominant notes . . .

*And this is exactly the sort of building that would respond best to your suggestion as to mechanization . . . to the largest possible extent, bringing everything on to the job with as much of the labours on it done in the factory as possible."*⁶⁶

Of course the glazed wall offered to do this better than the brick cladding that Mitchell predicted and it was in the post-war school building programme that this was to find expression.

In 1952 there were studies at Byanston School, designed by Architects Co-operative Partnership, in the use of curtain walling. The building was put up 'as an experiment in order to study, under site conditions, a new structural cladding system which is to be used for certain local authority school buildings.'⁶⁷ This particular building used T-section bars as the carrier for the glazing. Two years later Hope Windows used pressed metal covers over a 4 x 4 inch (100 x 100 mm) T-bar structural mullion at Coventry College of Art and Technology. As we have seen, this firm had already been able to export its expertise for the design of pressed-steel mullioned curtain walls to the States, although there is no indication

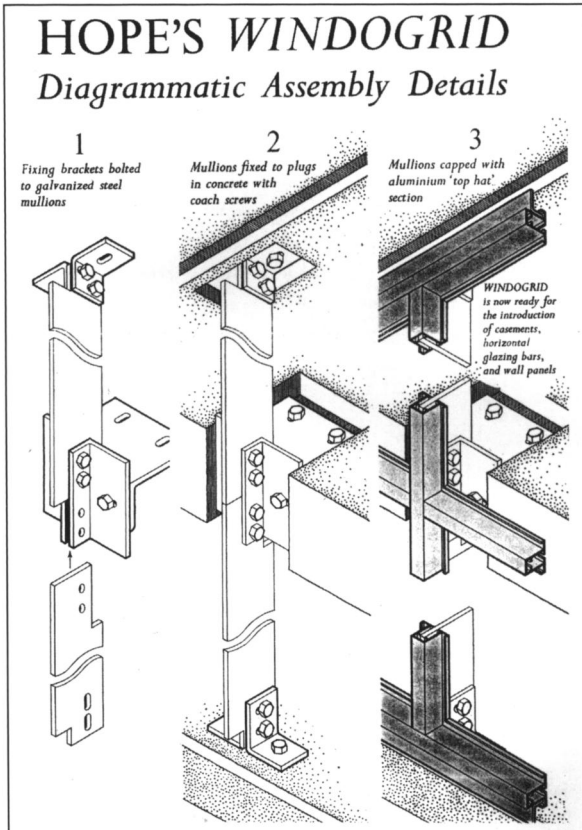


Fig. 13 Hope's Windowgrid System: diagramtic assembly (from Henry Hope and Sons Ltd., *Hope's Window Walls*, 1956).

that it was aiming to develop a market for a standard system there. But it seems possible that their experience with different pressings for each building would have demonstrated that a simple standard rolling as the structure, with a non-structural cover, would prove a more marketable system.

Their 'Windowgrid' curtain walling system, which was used for the LCC's Parliament Hill Secondary School relied upon simple galvanized steel bars to form the mullions, varying from a 3 x 5/15 inch to 4 x 3/8 inch section (75 x 8 to 100 x 9 mm). Rather than pressed metal, this was then covered by an aluminium top-hat section to carry the windows and a variety of wall panels, either glass, metal, plywood or asbestos based (Figs. 13-14). This system was ideal for the school buildings now so urgently wanted and it was Parliament Hill Secondary School that was prominently featured in their 1956 promotional booklet with a claim that 20,000 square feet had

been installed there.⁶⁸

When the construction of the school was reported in *Prefabrication* it was the aluminium rather than the steel that was emphasised in what was perhaps a misleading title.⁶⁹ But then there was a need to absorb the production capacity for



Fig. 14 The Windowgrid system in use at Parliament Hill School, London (from Henry Hope and Sons Ltd., *Hope's Window Walls*, 1956).

aluminium that had been developed in Britain during the war just as in the States, and the first British curtain-wall system to appear was an the aluminium structure of William and Williams's 'Wallspan'.⁷⁰ This used hollow extrusions to form mullions and transoms with special joint spigots to take up thermal movement, the whole system designed to carry any type of window and a wide range of infill panels.

By 1957 when Edward Mills produced his article for *Architect and Building News* which reviewed the state of curtain wall technology, these two were among several systems available.⁷¹ This was now an idea that was well established and, comparing the various systems, one can see how different companies had approached the idea from different angles, all by now anxious to get into the game. It was in November of that year when a solution was produced for the fire protection problem in the form of Gardiner of Bristol's 'Muragard' which was claimed to be the first curtain wall in the world to be given a two-hour fire rating.⁷²

Conclusions

The position in 1957 might have been that the curtain wall had become a new vernacular but only in the visual sense. In technological terms there were still a number of problems to be solved, particularly in the development of sealants. Also the various systems reported as part of Mills's article were far from similar in their technologies. Two were timber systems, some were based entirely on aluminium sections while others combined steel and aluminium. What followed was a period of development and competition between the various systems.

From the perspective of the late 1990s when panel systems have become as important as glazed systems, it is clear that both were technically possible much earlier. Both offered the advantage of a rapid enclosure of the building with prefabricated components, dispensing with rather clumsy heavy forms of construction that depended upon uncertain standards of workmanship. The disadvantage that the panel systems had to face was that there was no simple agreed aesthetic that might form the basis of a standard system. This is implied in the report of a conference dealing with aluminium cladding where Robert Matthew argued that this form of construction would '*depend on the closest collaboration between manufacturer and architect.*' Perhaps so, but that might not suit commercial architects or clients wanting to know what they are getting and when. The time was not yet right for metal panels.

I have not discussed the development of the various infill materials because, although these were to play an important part in curtain walling, they were unnecessary. Glass alone would have been sufficient for the development to be possible because a range of colours and surface finishes was available. But it was not the variety of glass that was critical, rather it was the introduction of the carrier systems that was the key. The factors that led to the preferential development of glazed systems were that they could easily be developed from an existing technology and so needed less initial investment. Moreover, there was an established architectural interest in their aesthetic possibilities. That the system could be developed from one-off buildings to something that could be sold to commercial architects or for public building projects had an obvious appeal. The breakthrough made by Hope Windows for example, was to fix relatively simply formed aluminium extrusions to a very simple carrier system. This and the other systems offered a measure of variety together with the predictability of standardization.

Acknowledgements

My thanks are due to Stephen Kelley for providing me with papers discussing early developments in America and to John Keenan for providing material from the CIRCA collection.

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- 1 William Aiken Starrett, *Skyscrapers and the Men Who Built Them*, (N.Y. & London, 1928), p. 1.
- 2 Stephen J. Kelley, 'Office buildings of the Chicago School: The restoration of the Reliance Building', in *Conservation of Modern Architecture (ICOMOS, German National Committee, 1996)* citing Federick Baumann, 'Improved construction in buildings', *Sanitary News* 3 (15 March 1884), p 123.
- 3 For example, no information has been obtained to enable the several years of development behind the Alcoa Building, and its contemporary the Equitable Life Building, to be considered.
- 4 I. McCallum 'Syntax: The Contribution of the Curtain Wall to a New Vernacular', *Architectural Review* 121 (1957), pp. 299-336.
- 5 Marian Bowley, *Innovations in Building Materials* (London, 1960), pp. 274-322.
- 6 Raymond McGrath, *Glass in Architecture and Decoration* (London, 1937)
- 7 Raymond McGrath & A. C. Frost, *Glass in Architecture and Decoration* (London, 1961).
- 8 These buildings are described in Grant Hildebrand, *Design for Industry: the Architecture of Albert Kahn* (Cambridge, Ma., 1974).
- 9 Reyner Banham, *A Concrete Atlantis, U.S. Industrial Building and European Modern Architecture 1900-1925* (Cambridge, Ma, 1986), p. 193. Gropius was working in Behrens's office at the time.
- 10 The windows are described in detail in Wessel DeJong, 'Preserving an image of modernity: the Van Nelle factories in Rotterdam, The Netherlands', *Window Rehabilitation Guide for Historic Buildings*, 5, (n.d.), pp. 87-93. This building attracted a number of articles in *Architectural Record* a few years after it was built: viz, 66 (Oct. 1929), pp. 387-90; 68 (Oct. 1930), pp. 332-48; 69 (May 1931), pp. 417-22.
- 11 See for example Wm Black (1915-16), 'The lines of industrial expansion after the war', *Kahncrete Engineering*, 2 (1915-16), p. 145. The importance of daylighting was also the theme of Chapter 5 of Moritz Kahn's *The Design and Construction of Industrial Buildings*, (London, 1917).
- 12 See David Cottam, *Sir Owen Williams, 1890-1969* (London 1986), p. 72. No source is given for this illustration.
- 13 Drugenfabrik und Versandhaus', *Moderne Bauformen* 32 (1933), pp. 335-42. This article included a detail of the glazing.
- 14 At the time details of the cladding were published in 'Design Details 33, *Daily Express*', *Building* 8 (1933), p. 105. Recent scholarship suggests that Sir Owen Williams was the principal designer of this building.
- 15 John Burchard and A. Bush-Brown, *The Architecture of America: a Social and Cultural History*. (Boston Ma., 1966). They note, p. 346, that a photograph of the building was later hung in the school of architecture in Harvard because of its prophetic nature.

- 16 Keith W Dills, 'The Hallidie Building', *Journal of the Society of Architectural Historians*, 30 (1971), pp. 323-29.
- 17 'The world's first glass front building' *Architect and Engineer of California*, 53 (1918), p. 73.
- 18 'An all glass front: some daylight features of the Hallidie Building' *American Architect*, 113 (March 1918), pp. 393-4; 'A glass fronted building', *Architectural Record* 44 (Oct. 1918), pp. 381-4. It was also the subject of a much later article, 'Hallidie Building, San Francisco', *Architectural Record*, 79 (1931), p. 131.
- 19 Reported in *American Architect & Building News* 92 (1907), pp. 123-5.
- 20 'Bazar de la Rue de Rennes', *La Construction Moderne*, 22 (1906-7), p.159 & pp. 281-3.
- 21 Rostislav Svácha, *The Architecture of New Prague, 1895-1945* (Cambridge, Ma. 1995), p. 270.
- 22 Fluorescent lighting developed largely during the Second World War for lighting factories
- 23 *Architect and Building News*
- 24 P. Scheerbart, *Glassarchitektur* (Berlin 1914).
- 25 Reyner Banham, 'The Glass Paradise', *Architectural Review*, 125 (1959), pp. 87-9.
- 26 Korn A, *Glas im Bau und als Gebrauchsgegenstand* (Berlin, 1929; reprinted 1967 *Design Yearbook*, London).
- 27 John Gloag, 'The transparent wall', *Building* 10 (1935), p 128-9.
- 28 E. G. Warland, 'Structural Glass', *Building* 10 (1935), pp. 140-47
- 29 See J. R. I. Hepburn, 'Glass as a structural material', *Building* 8 (1933), pp. 424-6.
- 30 'Universal House, London (Joseph Emberton)', *Building* 8 (1933), pp. 276-8.
- 31 *Hope's Window Walls*, Henry Hope & Sons Ltd, Catalogue (1956), p. 20. CIRCA collection.
- 32 S. B. Hamilton, *A Qualitative Study of Some Buildings in the London Area*, National Building Studies Special Report No. 33, (London, 1964), pp. 16-24.
- 33 *Hope's Window Walls*. They also made use of the building in advertising their product at the time - see for example *The National Builder* Dec. 1936, p. xv.
- 34 'St Cuthbert's Co-operative Association showrooms Edinburgh', *Architect and Building News*, 151 (1937), p. 88. This building is also covered by *Architectural Review*, 81 (1937), p. 65.
- 35 'Design Details 31', *Building* 24 (1949), p. 34.
- 36 *Glass*, 9 (1932), p. 353.
- 37 'The "Glass Age" arrives - the Kirk Sandall hotel Doncaster' *Glass*, 11 (1934), pp. 426-7 & 446.
- 38 For a description of the stand see *Builder* 151 (1936), p. 549. They may have been encouraged to improve the design of their stand in this way by the large number of stands in the previous exhibition where exhibitors had used their designs to good effect. Their 1932 stand could best be described as dowdy - *Builder* 143 (1936) p. 473.
- 39 'Princes St redesigned in glass,' *Glass* 15 (1938), p. 329.
- 40 These were The Strand, Bond St and Liverpool Street Station in London, Bournemouth and Liverpool waterfront. Members of the so called committee were Grey Wornum, Howard Robertson, Maxwell Fry, Raymond McGrath & F. R. S. Yorke.
- 41 They and other companies were also interested in promoting the use of glass block at the time.
- 42 *Glass* 15 (1938), p. 360.
- 43 'Fire resistance of glass bricks - report of official tests', *Glass* 15 (1938), p. 366.

- 44 H. R. Dowswell, 'Walls, Floors, and Partitions in the Tall Building', *Engineering News Record*, 106 (1931), pp. 319-22.
- 45 He reported satisfactory results with sprayed waterproofing which had been recently developed. Sarah B. Landau and Carl W. Condit, *Rise of the New York Skyscraper, 1865-1923* (New Haven & London, 1996), pp. 172-3, have recently pointed out that waterproofing of the masonry wall had always been an issue in tall buildings and that concern for adequate protection of the steelwork had discouraged some designers from using skeleton construction.
- 46 Robert L. Davison, 'New construction methods,' *Architectural Record* 66 (1929), pp. 362-85.
- 47 Robert L. Davison, 'The first all metal apartment house: Lake Front Building, Chicago', *Architectural Record*, 68 (1930), pp. 3-9.
- 48 A. H. Burr, H-R., Hitchcock, P. Johnson and L. Mumford, *Modern Architects*, (New York, 1932), pp. 172 & 176-7. Project for Lux Apartments, Evanston, Ill.
- 49 *Architectural Record*, 78 (Aug. 1935), p. 165.
- 50 Robert L. Davison, 'The better wall is coming', *Architectural Record* 100 (Oct. 1946), pp. 119-23.
- 51 William Lescaze and R.L. Davison, 'The curtain wall - missing component to the skeleton frame is brought several steps nearer commercial reality', *Architectural Forum*, 86 (May 1947), pp. 97-100. Lescaze, like Davison, had previously been involved in the design of prefabricated housing.
- 52 Robert L. Davison, 'The wall of self-framed steel panels' *Architectural Record*, 103 (Feb 1948), pp. 135-9. A search of Department of Commerce publications has failed to find any report of this work.
- 53 Robert L. Davison, 'The lightweight curtain wall the long overdue counterpart of the structural steel frames', *Architectural Forum*, 92 (1950), pp. 81-96.
- 54 'The Curtain Wall Comes of Age: first large scale demonstration of lightweight metal-faced curtain wall goes on view this month in two Pittsburgh projects,' *Architectural Forum*, 96 (April 1952), pp. 135-40.
- 55 *Architectural Forum*, (May 1943). It is difficult to estimate how advanced Belluschi was in his comments about the future for aluminium in comparison with thinking in Britain at the time. Although the Aluminium Development Association was formed in 1944, Post-War Building Studies No. 18, *The Architectural Use of Building Materials*, devoted only one paragraph to this material. See also comments on this by Bowley, op. cit.
- 56 *Architect and Building News*, 194 (1948), pp. 438-9. *Architectural Forum* also published an account of the completed building, 89 (1948), pp. 98-106.
- 57 'Lever House, New York: Glass and Steel Walls', *Architectural Record* 111 (June 1952), pp. 130-5.
- 58 Ted Ruddock, 'Charles Holden and the Issue of High Buildings', *Construction History*, 12 (1996), pp. 83-99.
- 59 He built a public building containing a market and civic centre in the Bvd. du General le Clerc (1937) which had metal panel walls..
- 60 'Metal faced buildings', *Building* 8 (1933), p. 3.
- 61 *Curtain Walls of Stainless Steel*, School of Architecture, Princeton University (1955). A summary of this was provided by McCallum, 1957. Also in 1955 the National Research Council's Building Research Institute published *Metal Curtain Walls* (Washington, D.C.).
- 62 This was a risk because there was no guarantee that they would be awarded the eventual

contract to make these.

63 'A hospital chain 250 miles long', *Architectural Forum* 99 (August, 1953), pp. 132-9.

64 *Truscon Standard Buildings* (Youngstown, Ohio 5th edition, 1921: author's collection).

65 Given the number of articles on hospitals that appeared in *Architectural Record* during this period, and the proportion in which these architects featured, Truscon may well have had expectations of a larger involvement in what appears to have been a major campaign of hospital construction.

66 Memo from Godfrey Mitchell to WHT - 11 July 1943. Wimpey Archive, presently held by CIRCA-WICCAD

67 'Studies at Bryanston School', *Architect and Building News* 202 (1952), pp. 630-3.

68 *Hope's Window Walls*. This system also eliminated the awkward timber filler pieces that had been used in their one-off designs for earlier buildings. In 1953 when Crittall windows produced their catalogue (*Crittall Windows*, Braintree: 1953, Published by the Crittall Manufacturing Company), there was no sign that they had any interest in the development of curtain wall systems in spite of their having produced the glazed wall of the Royal Festival Hall.

69 'Aluminium Glazed Wall Cladding', *Prefabrication* 5 (1957), pp. 249-52.

70 See *Building*, 28 (1953), p. 480.

71 Edward D. Mills, 'Curtain Walling', *Architect and Building News* 212 (1957), pp. 370-92.

72 'New Curtain Wall System', *Prefabrication* 6 (1958), p. 326.

73 *Building*, 28 (1953), p. 317-8.