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Ove Arup and Box Frame Construction

Graham Harris

INTRODUCTION

Following the First World War house-building in Britain had struggled to cope with a backlog of need. Targets were set by local authorities, but the building industry, still operating on a largely traditional basis, was unable to meet these requirements with the funding then available. However, as the 1920s progressed, there were some steps forward in achieving volume production, mainly for smaller components, steps which were individually of little significance, but collectively began to speed up the tempo of building productivity. There was almost no move to industrialize the production of the structural envelope. The Second World War retarded any progress in this direction by eliminating many of the specialist building contractors, as well as many of the small firms which constituted much of the building industry, not to mention the destruction of so much of the housing stock, particularly in the larger cities. It was into this situation that Ove Nyquist Arup (1895-1988) stepped in the post-war years, with a potential solution that was at the forefront of design and engineering technology, but at the same time, and in character with its creator, was disarmingly straightforward: box frame construction, and also developed from this, a flexible concept of building using systems of concrete slabs, both precast and in situ. In a more or less chronological approach, the origins and development of these ideas will be traced through the interwar, then wartime years, culminating in the eventual application of the ideas to built forms after 1945. The specific subject on which more light can now be thrown, however, is Arup's struggle to convince the authorities of the need to take a proactive role in modernizing the building industry, the proactive role he himself took, the vision he worked to realize and the dangers he warned about. Whilst the actual building types and processes he advocated became the subject of abuse in the rash of poor quality and socially unacceptable system-built housing in the 1960s, it becomes essential to realise the deeper ideals which lay at the heart of his suggestions, ideals about the whole process of design and construction.

Educated in Hamburg and Copenhagen, first in philosophy and then engineering, with a particular interest in reinforced concrete, Arup had spent much of his early career with Christiani & Nielsen until 1934 designing harbour facilities from the firm's branch in London. It was an introduction to Berthold Lubetkin (1901-1990) in 1933 and the promise of becoming involved in architecture (a profession he had seriously considered when training) that set him on a very different course. Christiani & Nielsen had no interest in becoming involved in architecture, so Arup moved to J.L. Kier & Co., becoming Chief Designer and a director from the outset.[1] Throughout his career to this time Arup had concerned himself with modern, simple and practical solutions that were necessarily economical, but also - and this is what marked him out from many other engineers and indeed some architects - solutions that were aesthetically satisfying. His collaboration with Lubetkin and Tecton, even when the latter partnership was breaking up, was to prove pivotal in the development of modernism in Britain, but particularly in the development of standardized structural types that were to have a substantial effect on housing in the thirty years or so after the Second World War.[2]

ORIGINS OF THE BOX FRAME

In 1933 Lubetkin was contemplating a solution in the manner of Le Corbusier for Highpoint 1, a

double cruciform block of flats at Highgate, London to house workers of the Gestetner company. Whether the decision to replace the columns and beams by load-bearing reinforced concrete slab walls on all but the ground floor was his own or Arup's remains the subject of dispute,[3] but the resultant Corbusian-looking edifice which became the flagship of British modernism actually held the germ of an idea that was to enable the eventual industrial production of the structural envelope of multiple unit domestic buildings: the concrete slab as a vertical load-bearing element, as opposed to the by then more traditional approach of a regular concrete beam and panel grid-framework, which was loosely derived from steel-framed structures[4] (Fig.1). The result was much tidier and more flexible in terms of interior and layout, being less encumbered with piers and beams, and this tidiness and flexibility became Arup's priorities in what was to follow. The façade, in the meantime, conformed very much to the Corbusian ideal which, at that time, was so seductive to the *avant-garde*. The construction of the block itself was greatly facilitated by a system of climbing shutters, adapted from the type used to build cylindrical silos, of which Arup had by then much experience.

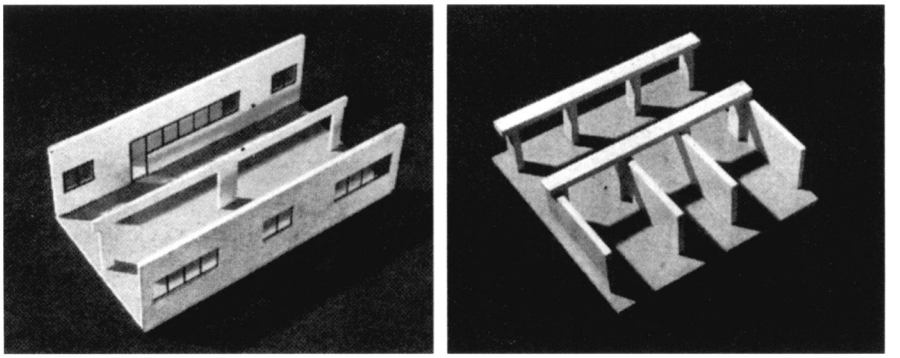

Fig.1. Structural forms at (left) Highpoint 1, and (right) Highpoint 2 (Courtesy Architectural Review, March 1951 p.139)

In Lubetkin and Arup's 1935 Working Class Flats competition entry, Arup retained the concept of load-bearing external walls but substituted the internal spine wall of Highpoint 1 with a more flexible system of flat columns and beams which could be arranged in a variety of ways so as to enable greater freedom of planning without the intrusion of these structural elements into room spaces, thus correcting the weakness of Le Corbusier's system used at Villa Savoye and elsewhere, but retaining the all-important flexibility of plan. At Highpoint 2 in 1937-38, a fundamental change was introduced in one side of the central sections of each block: in effect, sections of the load-bearing external walls were turned through 90 degrees to form cross walls, and these could form divisions between rooms or even whole apartments (Fig.1). This left the exterior open to be filled with a much more thermally efficient material than concrete, and gave much greater aesthetic flexibility to the architect. Perhaps more significant to Arup, however, was the planning flexibility enabled by this arrangement: room arrangements at front and rear of the block could still differ widely. The spacing between the cross walls need not necessarily be the same for each bay, though because the basic layout of each flat could be the same, external symmetry could prevail over the block as a whole. A sort of half box frame had been conceived. Coincidentally, similar box frame structural forms were being arrived at quite independently in Copenhagen at the hands of Mogens Lassen and Hubert Paulsen before the Second World War, both using the engineer Ernst Ishøy, and Arup was to acknowledge these later.[5]

In 1938 Arup left J.L. Kier to set up in partnership with his cousin Arne a number of companies engaging in engineering design, contracting and building supplies. Ove would also act in his own right as a consulting engineer. In the event the relationship did not work well, but through its duration of the war, Ove gathered a core of promising young engineers who were to help make up the firm he was to

establish in 1946. While engaging in practical design and contracting during the war years, Arup also worked on various theoretical design schemes for air raid protection, arguing that to concentrate personnel in safe reinforced concrete housing above ground was more practical, safer, and in certain ways more economical than to disperse them in lightweight huts with nearby underground shelters. The structural form of these "shelter boxes" was similar to the individual apartments at Highpoint 2, simplified to a basic box frame but where at the latter the sides were left open to be filled with variously, windows, or brickwork or other panel, in the shelters they were to be of reinforced concrete. Arup also drew up specifications for a more permanent hostel dwelling block, of the same basic structural form, but primarily for housing, with air raid protection as a secondary consideration. These box frames would have external walls of 14 inch brickwork, reinforced horizontally with steel, and buttressed with concrete, which could all be easily replaced in peacetime for domestic housing. No mention is made in Arup's publication "Safe Housing in Wartime" of the Highpoint projects from which these had been derived, and only a passing reference is made to the Danish models. They were presented rather as innovative solutions to the problem of protection from explosive blast, being based on highly specific and detailed calculations of various sizes of structure, and thickness of concrete which would give acceptable protection. Here was, in effect, the conception of the post-war multi-storey block of flats, and documentary evidence suggests that Arup had arrived at all this by around the end of 1940.[6]

Although the authorities showed no interest in Arup's proposals, he continued undaunted during the following war years to develop his ideas, particularly about how the box frame concept could be the basis for post-war housing and, to that end, some elements subject to standardisation and some even to prefabrication. This could at least apply to the shuttering required to cast individual wall panels in situ.[7] He emphasized the benefits of this structural type for its extreme simplicity of design, and its adaptability to the chosen method of construction; for its frequent repetition of identical construction processes, and the maximum use of labour-saving equipment. He even recommended its use for aesthetic purposes, the open ends of each "box" allowing the architect an empty canvas for individual creativity. Arup's box frame was derived not so much from sociological and architectural ideals which informed Le Corbusier's *Unité d'Habitation*, although these were still valid issues to him, but the concept was rather based on the hard economic and practical realities of engineering and construction processes. Arup regarded "simplification of design" as more exactly meaning "simplification of construction, in other words marrying design to construction, so that one suits the other" and placed particularly heavy emphasis on "rational organization of the work".[8] Thus the box frame was conceived, and its role in post war housing, at the heart of a drive for streamlining the building industry, for standardisation in work practices as much as anything else, all in order to achieve maximum efficiency, savings and speed, but with a result that was strong and durable, practical in use, and could bear the aesthetic of the architect's choice. All this was the subject of consideration and publicizing by the beginning of 1942.

DEVELOPMENT OF THE BOX FRAME PRINCIPLE

By 1943 Arup was turning his attention to management, systems, costings, and working methods in the building industry, as well as design details. The war factories now producing parts for military equipment could theoretically be re-employed under central authorities to mass produce parts for houses, schools etc. in peacetime. Arup was not alone in these notions: the concept of mass production was providing a model on which all sorts of possibilities were being considered. One particular feature which Arup began to concentrate on at this time was that whilst the box frame could ideally be constructed of reinforced concrete, traditional brick or block work and timber floors were also possible, and this would actually enable a more gradual transition from traditional to industrialized construction processes in the building industry. This could work particularly well if one further innovation was introduced across the board: dimensional co-ordination between the heavy structural shell and the factory-made parts was needed in order to streamline the building process.[9]

By this time Arup was collaborating with various architects including Cyril Sjøstrøm (later Mardall) in his investigations, but he had also joined two research committees: the Committee for Industrial & Scientific Provision of Housing (C.I.S.P.H.)[10] in 1941, a private initiative, and the Government's Ministry of Works Prefabrication Committee in 1942. The research he carried out for both of these into methods of streamlining production of post-war housing was to come to nothing within the committees themselves. The work of the C.I.S.P.H. was ignored by the government, and the Prefabrication Committee was just one of several such government committees, much of whose work was to suffer a similar fate. Arup later described the latter as "singularly futile"[11] in common with most government initiatives. This he found particularly disappointing since he realized only too well the enormity of the task in reorganizing the building industry to modern conditions, materials and technologies, and that such a task could only be achieved in an emergency with central leadership. However, there is irony here in that whilst Arup's research was in effect wasted amongst the committees for which it was carried out, it now formed the highly developed core of a campaign he conducted almost single-handed for the promotion of the box frame as the most logical way of exploiting all the qualities and benefits of reinforced concrete in post-war housing. Through the last two years of the war Arup worked tirelessly to expound the requirement for streamlining the building industry, for the standardisation of parts, if not whole structures, for the exploitation of prefabrication, for a universal standard within the country of dimensional co-ordination, and for the exploitation of reinforced concrete. Again, the logical, practical, economic and even aesthetic vehicle for all these, he argued, was the box frame. Papers such as "Concrete in Housing" and "Memorandum on Pigeon Hole Construction for Terrace Houses and Flats" lectures, meetings, correspondence and discussions with leading architects, key persons in the cement industry (such as Max Jensen of the Cement & Concrete Association) the professional press and others followed. The process culminated in the launch of his "Memorandum on Box Frame Construction for Terrace Houses and Flats" in May 1944. It described in great detail how the structure could and should be built, its qualities and benefits, graphically illustrated. Arup concluded with a plea:

> "...it (is) possible to launch an immediate attack on the housing problem. Concrete is one of the few building materials which can be relatively easily supplied at present. It will, therefore, be possible to make an immediate start on the provision of 'Box Frames' for post-war dwellings...The 'Box Frame' can, if desired, be considered as a permanent site for a light mass-produced dwelling of a partly temporary character, which can be improved later with a minimum of waste."[12]

This was followed with an undertaking that the box frame would:

> "...provide an improvement in the construction of dwellings without adding to the number of proprietary 'Systems'. 'Box Frame Construction' is not patented in any way, it is only an application of known structural principles which anybody is at liberty to use."[13]

Around 117 copies of this definitive document were circulated just two days after D-Day in June 1944 and hundreds more thereafter, right into the 1950s, to architects, borough and corporation engineers, surveyors and works departments, cement companies, the various engineering institutions, structural engineers, town planners, government ministries, and in response to requests from Russia, Canada, New Zealand and Jamaica. In a sense this dissemination could be interpreted as a latter-day equivalent of Vitruvius Britannicus in the eighteenth century, though it obviously concentrated on principles rather than built examples.

In October 1944 licences were being offered by the Ministry of Works to build experimental houses and Arup collaborated with Yorke, Rosenberg & Mardall to produce an experimental Box Frame House at Codicote, Hertfordshire, with the support and endorsement of both the Cement & Concrete Association, and the Cement Marketing Company. Of only two storeys, the house was intended to show

the principle could be applied to one of a potential row of similar structures and indeed was illustrated as such in the architectural press.[14] This model served to show how the type could be used on a small scale as well as for the larger structures envisaged by Arup. On this scale brick or block work could be used just as effectively for the cross walls - whatever was most efficient for cost, ease of construction etc.

It was around this time that the coverage and reviews of the Box Frame Memorandum began to proliferate, both paraphrases and commentaries in the architectural press.[15] An over-excited press exaggerated Arup's role, elevating him to the status of "inventor" of the concept,[16] extraordinary given that he had published a picture of a Danish pre-war example in an earlier paper.[17] With characteristic probity, he felt obliged to respond in the following issue:

> "I do not think Box Frame construction can quite rightly be termed an invention, but if it is, the inventor must be sought elsewhere. I have invented the name, and also advocated the use of this type of construction as a means of standardising and thereby facilitating large-scale building...[The box frame was]...more a logical development of building, arrived at independently in many places."[18]

Sensing that, although the war was coming to an end, there was something of a collective but ineffectual panic in official circles on the approaching post-war housing problem, Arup began to intensify his campaigning in the Spring of 1945, issuing to various associates what he called an "Easter Manifesto", later published in the *Architects' Journal*, in which he claimed:

> "...the main trouble which clogs the government's frantic efforts to do something about the housing problem is that the thing is far too complicated for anyone to comprehend. There is a crying need for simplification. Such simplification is usually brought about by standardisation, but standardisation is a very dangerous weapon if used indiscriminately.
> The merit of Box Frame Construction is mainly that if it were used for a substantial part of the building programme it would confer some of the main benefits of standardisation without its main draw-backs."[19]

He pondered the possibilities of promoting the cause more forcefully direct to those responsible for the big planning issues of the day - bodies such as the London County Council (L.C.C.) - rather than central government in whom, by then, he had little confidence. This was a course of action that was to have far-reaching consequences. Meanwhile campaigning for the adoption of the box frame continued apace with all the advantages spelt out to various audiences time and again. One particular argument frequently posited by Arup was that the box frame was formed of a limited number of frequently repeated surface elements which obviously lent themselves to standard units of shuttering. In a climate of increasing clamour in the architectural press for ways and means to standardize and to prefabricate, this was one of the more practical measures suggested.

In June 1945 Arup began to conceive a variation on the relatively rigid box frame: an altogether looser arrangement which prefigured later system building (Fig.2).

The basic purpose of this was to enable greater flexibility of layout than box frame construction had hitherto allowed, yet avoiding the customary columns and beams which all too often intruded into the room spaces of traditional column and beam structures. The building components on which this system was based were the usual reinforced concrete slabs for floors, ceilings and occasionally walls, and "wall-strips" - supporting members no more than 6 inches wide, spaced between 5 and 8 feet apart. Wider intervals would require a third element, beams, which would be of the same thickness as the strips, and depth being decided by the height of door openings below. What in effect would become "pierced walls" or "wall frames" could then be filled with a lighter material of whatever thermal and sound resistance was required. The system could of course be used in combination with elements of the box frame in any

situation. In an unpublished paper of July 1945[20] Arup qualified his revised classification. What he previously referred to as "box frame construction" he now stated was a system embodying a general principle. He referred to this principle as "Slab Construction". The latter had now become in effect the main structural system, which could freely use slabs, strips and beams in various combinations, but where mainly slabs were used for walls, a "box frame" could result.

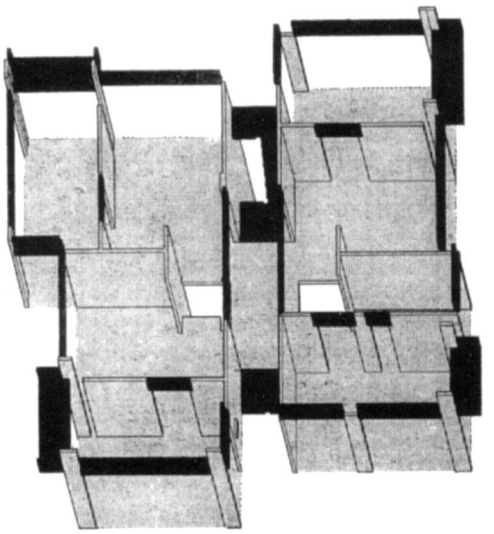

Fig. 2. A later example of slab, wall-strip & beam construction by Arup: in situ cast slabs and strips shown in grey, pre-cast elements in black (Cleeve Barr 1958 fig. 73.)

In his campaigning for the adoption of the box frame as a vehicle for standardisation within a reformed building industry, Arup's persistent arguments for dimensional co-ordination to be government-led were often accompanied by a rejection of what might seem logical in a building type based on repeated identical elements: the concept of modular planning. He had given the subject much thought and had inspected details of initiatives in America. In correspondence of March 1946[21] he criticized various contemporary ideas of modular planning, he accused some theorists (e.g. A.F. Bemis) of having omitted to take into account the thickness of structural members intruding into the modular spaces. Furthermore, the whole concept, while theoretically enabling great flexibility of planning, relied on standardized parts which would in practice be supplied by a number of different manufacturers. There would be inevitable consequences of minor differences in fit, unless the whole system was under one very large organizational umbrella. Time and time again Arup tried to convince his audiences that standardisation did not just concern mass-production of identical components, but more usefully, standardisation of their relationships, one with another. If box frame construction could be planned using a limited range of standardized shuttering sizes, with resultant standardized slabs, and these were related to similarly gauged external wall infill panels, an organizational economy would result. This was the most logical and practical basis from which to progress in the drive towards standardization. Furthermore, Arup pointed out that standardisation generally followed in the wake of accepted practice but in the post-war emergency, there was a need to standardise *ahead* of practice.[22] It was because of this that, ideally, central government should play a key organizational role. Papers proposing such ideas proliferated from Arup's desk through the late 1940s, often repeating the same or similar arguments.[23]

While Arup had been promoting the box frame, slab construction, and reinforced concrete in housing generally, it had not escaped him that many of the existing building standards and regulations were

obsolete or inappropriate for the economic exploitation of the material. Hitherto, for instance, a load-bearing concrete wall had, officially, to be calculated as a column. The regulations governing a column were based on the assumption that it would be fully stressed, an assumption which actually rarely applied to walls. Arup took the initiative in December 1945, calling on the Ministry of Works to arrange tests. Actually the Building Research Station (B.R.S.) already had a programme of such tests scheduled, but on Arup's prompting, these were given much higher priority.[24] Arup was consulted about practice elsewhere and as a result found himself liaising between authorities and specialists in Denmark (Ernst Ishøy) and Sweden (Professor Hjalmar Granholm), passing on detailed information to the B.R.S., and to the Ministry of Works, Structures Panel, together with his own critical assessment of the situation and comparison of Scandinavian practice with that of the L.C.C.[25] Because of the apparent urgency of post-war reconstruction, Arup called for interim or temporary regulations for walls so that builders could proceed with using reinforced concrete in a more rational way, while the B.R.S. deliberated. By 1949, once the B.R.S. had completed their tests, the results confirmed Arup's preference for the slab rather than the column for many purposes. The danger of buckling was shown to be much smaller in thin walls than for columns of the same slenderness ratio, and Arup was to use this to promote further employment of the slab. This was not the only business he had with the B.R.S.: an experimental box frame block was required for investigation into sound transmission and Arup's firm was commissioned to construct this at Abbott's Langley. Arup was, it would seem, at the centre of many such developments in building research, at least in Britain.

REALIZATION OF THE VISION

It was while all this had been going on that Arup began in 1946 the dissolution of the partnership with his cousin Arne and the establishment of his own organization. As well as working within the partnership, Ove had from the outset been working through the war years in his own right as a consulting engineer, and it was this side of the business entirely that he now wished to pursue. As mentioned, many of those who now formed the backbone of his new organisation, (known simply at first as "Ove N. Arup, Consulting Engineer") had already been gathered around as employees of his wartime practice, most notably a brilliant mathematician Ronald Jenkins, but in total the fledgling firm numbered no more than 20. It was not until 1949 when Ove began asking some of these to join him as junior partners that the firm became "Ove Arup & Partners, Consulting Engineers". Rapid growth followed, as work picked up with postwar reconstruction, and talented young engineers from many countries were attracted by Arup's burgeoning reputation for quality, innovation and efficiency.

Some of the work which was to attract such attention was a piece of unfinished business in Finsbury with Arup's former collaborators, Lubetkin and Tecton. All the theoretical and promotional work on the box frame had simply been the groundwork to enable such building projects at the cessation of hostilities. Although not the first postwar box frame block of flats - that was a relatively small development at Kenmure Road, Hackney of only four storeys and penthouse, a size which did not fully exploit the economies of scale Arup mentioned in his "Easter Manifesto" - Finsbury was to be the real test bed for the theories developed during and after the war. Designed originally by Tecton and Arup in 1937-9, the Spa Green Estate (Rosebery Avenue), Finsbury, (Fig. 3) was built to a modified design in 1946-9, and this really was the first major (postwar) box frame block of flats in Britain.[26]

The cross walls were only 5-7 inches thick, the floor slabs 4.5 inches. Difficulties were experienced with the shuttering, with achieving accurate verticality and with developing a plaster mix which would adhere successfully to concrete. The innovative Danish system of shuttering adopted did, however, ensure that the whole project had the potential to be very economical, requiring less skilled labour. Experiences of the systems adopted were then to be used in modified form at the larger project at Busaco Street, Finsbury, (1947-52). Peter Dunican, one of Arup's first partners, was to comment later on the significance of these Finsbury projects:

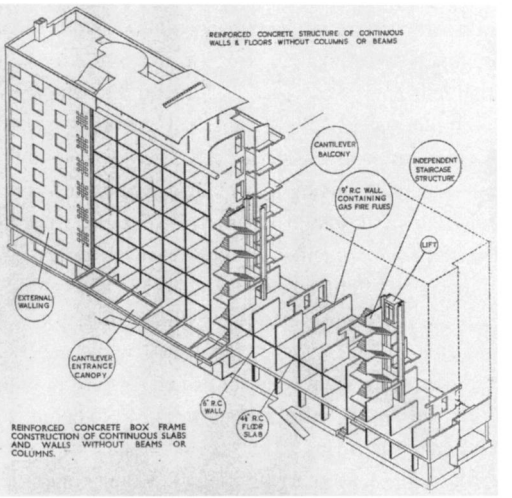

Fig.3. Cutaway section of the box frame flats at Rosebery Avenue, Finsbury by B Lubetkin with O Arup
(Courtesy The Builder, 2 August 1946, p.113)

> "These two jobs undoubtedly established a standard of design in low cost housing, both architecturally and structurally - and this standard has more than stood the test of time. The fact that we lost quite a lot of money on them is now perhaps by the way."[27]

It should be noted that both Arup himself and Dunican were highly motivated by an agenda of social responsibility, not that uncommon in the postwar years, and by this time it was increasingly Dunican and the other partners who were more personally involved with the design and execution process, Arup himself taking a more overseeing and public role as head of the firm.

At a time when most British architects were concentrating on two-storey suburban structures, Arup was experimenting with all that he had developed through the war years, and his firm in collaboration with Tecton was almost alone in breaking new ground with the development of multi-storey domestic blocks in reinforced concrete. As with much experimental research or prototype work, the cost, as Dunican stated, was high. The era of the tower crane had not yet arrived and the difficulties were considerable, but much was learned, many problems ironed out so that the next major project, the Hallfield Estate, Bishop's Bridge Road, Paddington (1947-55)[28] was more certain to make a major impact in British architectural and building history. The system used was part box frame, part slab construction. Thin concrete load-bearing wall panels were used to serve a practical layout of each flat, putting into practice some of the benefit of the tests that had been carried out at the Building Research Station. As Dunican wrote in retrospect, "broadly this scheme put cross-wall construction on the map."[29] Dunican may have been expressing a view that was coloured by his own position in Arup's partnership, but there seems to be little evidence to refute this claim.

The real economies to be accrued from moving further towards slab and wall strip construction only began to become evident with a point block structure engineered by Arup at the Fitzhugh Estate, Wandsworth (1953-5). Here the total cost per flat was actually less than that of flats in a roughly contemporary (1954-7) much larger slab block at Loughborough Road Estate, Lambeth, which contained twice as many flats, and used a full box frame system, but where the L.C.C. employed another engineer.[30] This highlights the fact that Arup was not hidebound by the type, as others were to become, but was constantly seeking the most appropriate principles and solution to the project requirements.

To some extent, slab and box frame construction benefited from the general steel shortage from 1947, and the fact that reinforced concrete technology had progressed greatly during the war. Arup had shown the potential of the box frame and slab construction principles and, although popular with many architects, engineers and local authorities, particularly the L.C.C. for whom Arup worked, it was widely but not universally adopted. Whilst Arup had worked out ways of enabling planning flexibility, others only saw the restrictions that slabs imposed. Perhaps more significantly, one of the more worrying problems with box frame construction which deterred some from using it in large multi-storey developments, was that of ensuring longitudinal stability. However, as Dunican and Cleeve Barr explained, there were satisfactory and economic solutions even to this, such as strategic use of stairwells and lift shafts.[31] The perseverance of Arup and others responsible for the initial development, even to the extent of incurring financial loss, is perhaps an indication of their conviction and belief in the future of the principle, while others less involved were less inclined to engage with a technology that was still in many ways experimental. Moreover, this might also indicate the extent to which Arup engaged in close collaboration with architects in the design and construction process, in a way that was still outside the experience of most in the two professions.

It has yet to be ascertained to what extent the lead taken by Arup and the dissolving Tecton partnership in experimenting with large multi-storey developments was responsible for luring other architects and engineers to do the same. But during the 1950s the transfer of interest from prefabricated two-storey houses to such developments became inexorable, the attraction of pioneering a brave new world of *Zeilenbau* or picturesque estates irresistible. The introduction to Britain of the tower crane around 1950 was obviously a factor, enabling economic building of greater height, but research into even this development is required in order to ascertain the extent to which Arup's projects were influential. With the new interest in high flats came a requirement for architects and engineers to collaborate more closely, and indeed to extend that relationship also to the contractor,[32] all pathways which Arup had trod before and had campaigned tirelessly to promote. In particular the design and construction of flats at Picton Street, London by the L.C.C. and Arup in 1955-7,[33] involving collaboration with the contractor from an early stage, was the subject of much press coverage at the time. Coincidentally it was Picton Street which was to reveal the extent to which prefabrication of concrete elements could be exploited, and additionally, handled with increasing ease by the new tower cranes. Interest was now being aroused in all these new processes of construction, and how they could be expressed architecturally. The box frame, as Arup had pointed out for years, was the realization of principles and processes as well as a type, and it lent itself to all manner of tectonic architectural expression. The real work of the engineer was at last beginning to be recognized as worthy of being deemed architecture. The days of architects trying to design structures that in some way had an appearance of modernity, often by simply emulating one of the early heroes of modernism, were over. A new standard had been set, but would it be followed?

THE VISION TURNS TO NIGHTMARE

We started by looking briefly at the situation following the First World War, and the inability of house-building organisations to meet targets, due variously to lack of funding, and the use by the building industry of largely traditional techniques and materials. The former problem was obviously shared by the post-Second World War generation, and indeed the building industry was still hampered by traditional organisation and practices. The initial need for repair and replacement of war damaged property, then the desire to replace the insanitary "slums", and the requirement for housing following the economic and baby booms of the late 1950s, all required a more streamlined approach. The initial socialist planned solution from 1945 gradually broke down, giving way in the 1950s to the increasing involvement of private capital. In 1954 old building controls and byelaws were swept away to enable higher population densities, higher blocks, greater speed of construction and potentially higher profits. Public housing, which started as the domain of local authorities with their architects and engineers, not

least that of the L.C.C. in its halcyon days of Roehampton and other flagship estates, became turned over to commercial developers and industrial interests.

By around 1960 the commercialization of housing in many cases seemed more akin to crisis management than considered and calculated action. Industrialized system building seemed to be working in Europe, so one solution was to simply import the continental systems wholesale. The other was to develop some home-grown varieties as quickly as possible. The resulting ill-considered speed and targets which the whole system imposed on itself - central government, local planning authorities and other departments, industry, designers and others - became one of the greatest weaknesses of what was to have been the solution. The whole building effort became overtaken by a frenzied race to produce quick results and to meet arbitrarily chosen targets, and the only way of meeting them was to adopt standardized prefabrication *en masse*. As early as 1943 Arup had foreseen the "...problems which prefabrication will bring to the fore ... careless waste, nefarious practices and atrocious designs, unless the thing is tackled firmly from the government's side, and there is, of course, not the slightest chance that it will be so tackled."[34] The warning that Arup had given in his "Easter Manifesto" of 1945 that "standardisation is a very dangerous weapon if used indiscriminately" (quoted above) was vindicated. Yet it was Arup himself who had proposed the box frame and slab construction which were specifically designed to maximize the economic and other benefits of standardization and prefabrication. What had gone wrong?

Arup had envisaged a well designed model, or models, developed by teamwork and intensive research, erected by professionals on sites that had been chosen and laid out for the long-term public benefit, all within a building industry which would need to have been reorganized by the government in the prevailing emergency. But this was idealistic and, as he predicted, incapable of being government led, except for the provision of research and testing facilities, mainly because of the complexities involved. The box frame concept embodied the required simplicity and, given the flexibility of material - traditional masonry and timber or industrialized concrete - could have enabled a relatively gentle transition of the building industry from traditional to industrialized basis. However, where it was used, as for instance at Loughborough Road, it was not necessarily to maximum advantage, as the comparison with Arup's Fitzhugh Estate (above) showed. Indeed, it is likely that the box frame was sometimes chosen more for its Corbusian or Brutalist imagery by architects wishing to display their avant-garde preferences, rather than for reasons propounded by Arup. The type had undoubtedly sparked much interest amongst the architectural profession whose enthusiasm for any such novelty was great. But Arup did not see it as such; box frames were practical, economical and appropriate in some situations, but not others: in 1953 he was attempting on behalf of the L.C.C. "...to find something which will be more economical than box frame construction," for some proposed 11-storey flats, but confessed "whether we will succeed in this, I do not know."[35]

The ill-considered lurch into under-developed system building by commercial interests, that was loosely derivative of Arup's slab construction concept, was made for reasons largely to do with political expediency, with predictable consequences. As Arup foresaw in 1945, "private enterprise is probably not able to tackle the problem in a sufficiently comprehensive way, it is more likely to develop schemes for the exploitation of particular materials or industries."[36] And so it was. In any event, the initial models or systems which were developed commercially may have been subject on the drawing board to an architect's eye, and an engineer's calculation and specification, possibly even in consultation with each other, but their deliberations were rarely translated in entirety to the production and assembly processes.

So the system building revolution began and, unwittingly perhaps, Arup had been instrumental in some of the material principles employed, and indeed even in the introduction of some of the main players: in 1951/2 he introduced one of the more important sources of later systems to the L.C.C.: the Danish firm of Larsen & Nielsen.[37] The firm's system was adapted by Taylor Woodrow-Anglian and then used by the L.C.C. from 1963.[38] How and from where Larsen and Nielsen and other continental system builders had derived and developed their expertise in system building is not the subject of this

paper, but the principal proponents in Britain had for some time been Reema Construction, Hampshire[39] and it was Arup who personally arranged for R.A. Larsen to visit the Reema factory in November 1950 when the Danes wanted to see their precast concrete "façade elements".[40] Whilst no particular conclusions can necessarily be derived from these contacts, the possibly pivotal nature of Arup's position between developments on the continent and in Britain cannot be ignored.

CONCLUSIONS

As he often pointed out, the box frame was never Arup's invention. Box frames arose independently in various places and continued to be built quite independent of anything Arup may have said or done ever since. Indeed it might be argued that Le Corbusier's "bottle-rack" concept expressed in the *Unités* was more influential in many respects. As regards the basic structural type itself, it was the act of development and exploitation by Arup of the simple idea at a time when there were few other serious contenders in the development of industrialized massed housing in Britain that was so significant. His technical understanding, energy, commitment, and the application of his many social and business skills were all instrumental in realizing his vision of what could be done with this simple building type. Undaunted by ineptitude, indifference or inertia in bureaucratic circles, he persisted with theoretical and practical development of all aspects of the design and construction, even to the extent of financial disadvantage. As a result the Finsbury projects were leaders of their kind in Britain. The international co-ordination he arranged was to enable and to expedite the revision of building regulations for reinforced concrete, opening the way for more efficient structural design and more appropriate exploitation of the qualities of that material. The promotion of dimensional co-ordination doubtless added to the weight of pressure to gradually bring results also.

His efforts provided the means for architects to escape from dependence on the load-bearing external wall; to escape from the limitations of the Corbusian "free façade", providing the opportunity to explore new possibilities, elevations which could be interpreted with brutally tectonic simplicity, (as in the box ends of the Roehampton West slab blocks), or as geometrically decorative as a traditional Caucasian rug, (as in Lubetkin's later works in London). He provided the means to escape from the untidiness of the old column and beam structural format, which bedevilled the planning of so many interior spaces. In doing all this Arup turned Le Corbusier's attempts at an architecture which had the appearance of modernity and an engineering aesthetic, into an architecture which actually reintegrated the roles of architect and engineer.

But that was only the box frame structure itself. For Arup, box frames were simply a method of standardisation. They, and buildings of slab construction were merely the most suitable vehicles for particular principles and processes and as such, he contended, happened to be particularly appropriate for the situation in a country where there was an emergency need for re-housing on a vast scale, when the building industry was still largely in its historically traditional forms and practices, and when central government had proved itself incapable of offering leadership in its reorganization, due to the immense complexities involved. The box frame and slab construction brought the potential for simplicity, and for economy, when and where they were needed, but these were not to be substitutes for high quality of design and execution, either in the initial build, or in maintenance and adaptability throughout their lives. If designed and constructed to those high standards, such buildings had the potential to bring satisfaction to those dwelling within, indeed to the wider community, and this should have been long-term satisfaction. These were the issues that mattered to Arup. Where and whenever these principles are adhered to in industrialized building then and ever since these are, in effect, the legacy of Arup's aspirations for the box frame.

But more even than that, he always saw the means to achieve these as being as important as the ends themselves: the close collaboration, the teamwork amongst the professionals, authorities and industries involved at each step of the design and building process, even down to the welfare of the individual

building operatives: this has been the cornerstone of the partnership's method of working, throughout the world, ever since. Indeed, the setting up of Arup Associates in 1963, an integrated practice of architects, engineers and surveyors, was perhaps the ultimate embodiment of these principles. The fact that collaboration generally amongst architects and engineers has been such a live issue ever since, and indeed so many large firms of similar professional content have been arising all over the world for some time now, is perhaps the ultimate legacy of the box frame. Box frames are still being built today, some well, others badly, everywhere from Edinburgh to Shanghai. There is a danger of attributing all, including the worst of postwar developments, to Arup's influence. To do so would be to misinterpret and misrepresent his vision, his standards and his professionalism.

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Correspondence: Graham S. M. Harris MA (Hons) PhD FSA (Scot), Dept. of Architecture, University of Edinburgh, 20 Chambers St., Edinburgh EH1 1JZ.

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