Ideal Structures & Urban Context
Strategies for integration of ideal spatial structures and place: Virum Sports Hall designed by Finn Monies & Jørgen Nielsen

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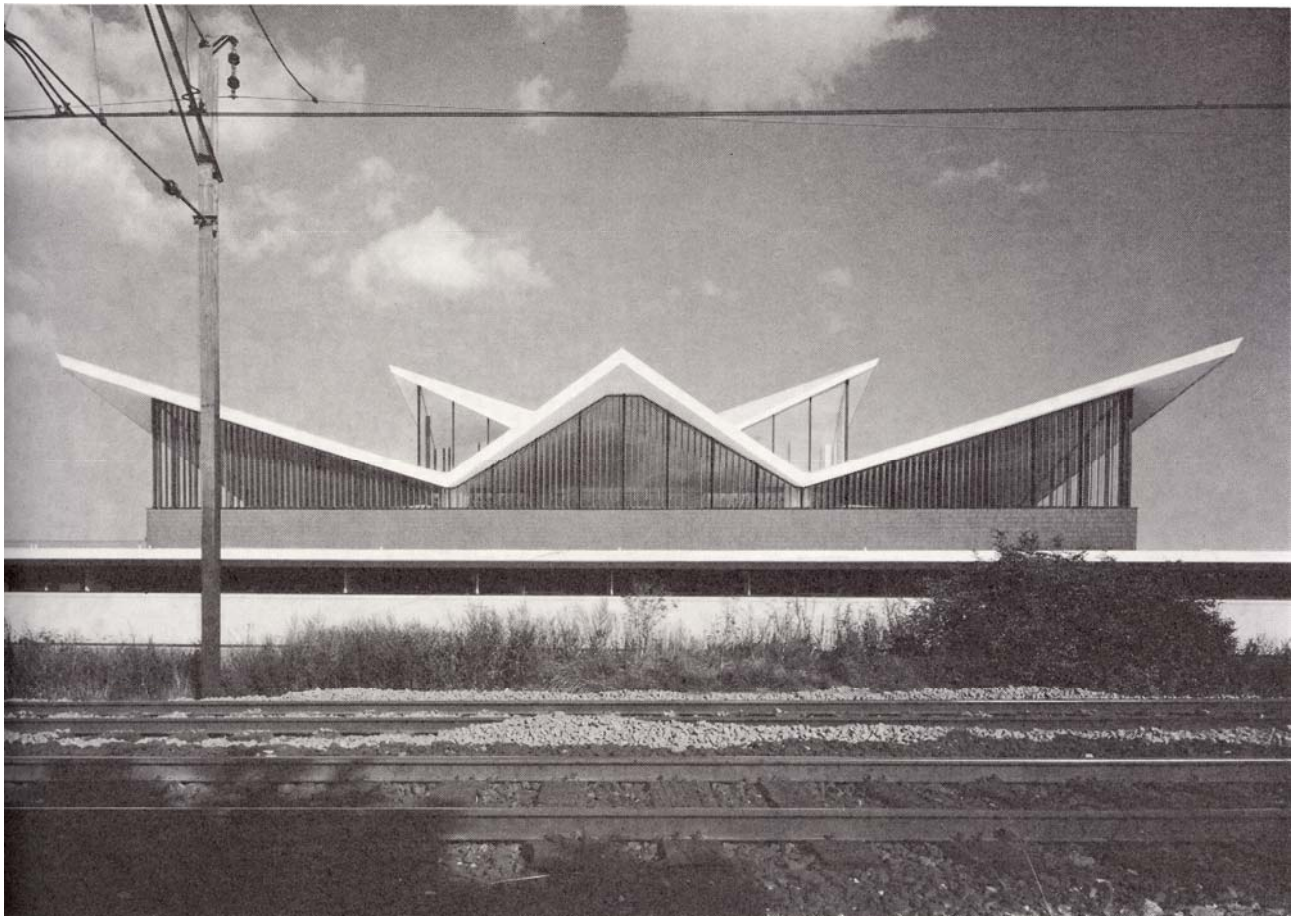


In his classic essay, '1960: Stocktaking', American architectural historian, Reyner Banham unfolds an inquiry into the bonds between technology and architecture in the year 1960. Here, according to Banham, technology and science did not serve as inspiration for abstract aesthetics and 'logic formalism', as is now the general conception of earlier modernisms. In the 1960s, the works of engineers like Eduardo Torroja, Felix Candela and Nervi were given full expression in their own right, the engineers being credited almost more than the architects.[1]
The prominent role of engineering structures in the architecture of this period gives us the opportunity to study relationships between engineering following its own scientific logic – which could serve as a first definition of the term 'ideal structures' – and architecture concerned with context and space. The Virum Sports Hall, designed by architect Finn Monies and professor, civil engineer Jørgen Nielsen in 1968, is part of this agenda, but as we shall see some special Danish strategies evolve from the meeting between 'ideal structure' and the architectural ideas of Finn Monies and 'the Golden age of Danish Modernism'.[2]

Jørgen Nielsen, gives an outline of the discussion in the first pages in his book, 'Idé, kraft, form', where he describes the architect as concerned with simple geometric shapes and the engineer focusing on structural

[1] Banham Reyner, A Critic Writes, Los Angeles 1996, p. 55 '*This sincere flattery of technology Is one facet of the almost fetishistic regard afforded to certain classes of engineers, an admiration that has undergone an important change in the last decade. The respects paid by the early masters of modern architecture to the engineers they admired was not paralleled by any attempt to mimic the forms of their work – where will you find Freyssinet echoed in early Corbusiean design, or Maillart in max bill despite the latter being the great bridge builders devoted biographer? Yet nowadays the desire to incorporate engineering forms into architectural design is so overwhelming that engineers like Nervi, Vandela, Torroja and others enjoy a status both as collaborators with architects and as the creators of imitable forms, that engineers have never had before.*'
[2] Expression produced by architectural historian Lisbeth Balslev Jørgensen, describing the heydays of Danish modernism. Arkitektur DK 1992 p 98 - 111

mechanics. The complementarity between architect and engineer is that between geometry and structural mechanics. [3]

The traditional idiom of architecture is that of rectangularity, fused to perfection down the centuries with the skills and tools of craftsmen. Both the traditional compact city and the 'garden city'-style suburb of the 20th century grew out of this set of ideas. The contours of a conflict appear in both Reyner Banham and Jørgen Nielsen's observations: engineering following its own scientific principles almost invariably ceases to be rectangular in its format. [4]
New and innovative ideal structures, first and foremost the big category of spatial structures, tend to ignore the aspect of context. The laws of nature work universally, so why adjust to a context? R. Buckminster Fuller's structures can serve as examples of this 'newly-landed-spacecraft' character. But due to special Danish circumstances other more complex strategies have appeared for the relationship between ideal structures and their surroundings.

Virum Sports Hall is an example of the acknowledgement of engineering principles shaped in the architecture of the 1960s, but at the same time it was created by profiles with long experience in traditional Danish architectural practice. By making explicit the ideas behind this architectural tradition as well as the ideas and principles involved in the work of engineering at Virum, they demonstrate strategies for integrating ideal structures with place.
Virum Sports Hall is studied as a case, based on observations of its present state, literature on the building and its surroundings, interviews with the engineer and architect, and analysis of the construction drawings. Finally Virum Sports Hall is compared with other buildings of the period with parallel agendas.

Contextual Strategies of 'the Golden Age of Danish Modernism'
'The Golden Age of Danish Modernism' is a term launched by Danish Architectural Historian, Lisbeth Balslev Jørgensen, to describe architectural production from the mid-1950s to the late 1960s. This is when internationally renowned architectural masterpieces, such as the Louisiana Museum by Bo & Wohlert, were built, but more important was the generally high level of building culture manifest in e.g. one-family houses, municipal offices, schools, etc. A short description could be: Frank Lloyd Wright interpretations blended with the deep-rooted Arts & Crafts-inspired ideology present in the 'Klintian School'. Professor Kay Fisker used this term to describe a set of tectonic and contextual ideas explored by P.V. Jensen Klint (the designer of the Grundtvig Church) and his successors, who were all professors at the nation's only school of architecture.[5] Tectonically they were strongly opposed to Arne Jacobsen's all too cold (in their view) Miesian steel-and-glass-Modernism[6] and instead favoured solid 'vernacular' materials, left in their natural finish with visible joinery.[7] During this period Kay Fisker, Wilhelm Wohlert and Finn Monies among others took an interest in Californian Arts & Crafts masterpieces by e.g. Greene & Greene, Maybeck, etc. [8] What they found was a confirmation of the tectonic programme inherited through P.V.Jensen Klint from William Morris and John Ruskin[9] and at the same time new fuel for their growing fascination with the vernacular architecture of Japan.[10]

Finn Monies holds a special position in this context; His architecture making use of the tectonic idiom of the Klintian School but at the same time manifesting openness and interest in innovative structural principles. Finn Monies and Jørgen Nielsen taught together at the Royal Academy and the Virum Sports Hall was developed in a harmonious balance between an architect and an engineer that knew each other very well professionally. Finn Monies has described how the process was initiated: 'Jørgen and I sat down at a table with my first sketches. I had an idea of the general layout of buildings. Very soon we agreed that the Sports Hall could not have a simple flat roof and of course we needed a great span in order to avoid disturbing supports. We discussed different structural principles and gradually the principle of the folded plate came to

[3] Nielsen Jørgen, 'Ide Kraft Form', Copenhagen 1998, p. 23
[4] Banham, opus cit. p. 57:
'However, it should be noted that when prefabrication gets out of the direct control of architects, into the hands of engineers, it almost invariably ceases to be rectangular in its format. Fullers work is again a case in point, so is that of Jean Prové, which has persistently relied on tapered portals, sloping walls and curved members…*
[5] Royal Academy of Art founded 1754 (Aarhus School of Architecture founded in 1965)
[6] Wohlert Vilhelm "man skal være ydmyg i sit udgangspunkt" (interview)*Arkitektur* DK 1991 p.339
[7] Petersen Gunnar Biilmann "Kaare Klint, "traditionen, naturen og kunstneren" Arkitekten#7 1956 p.100-101.
[8] Monies, Finn, Arkitekten 1968 Nr.26 Side 571-575
Wohlert Vilhelm, "En amerikansk arkitektskole", *Arkitekten* 1954 s. 189-193
Fisker Kay "Bay region-stilens ophavsmænd", *Arkitekten* #2 1962 p.23
[9] The tectonic programme of the 'Klintian school': Fisker Kay, "Den Klintske skole", *Arkitektur* 1963, p.43, Frampton Kenneth 'Studies in Tectonic Culture' MIT 1995, p 259, Bjerregaard, Lotte Marianne, Forsegling & Symbiose' Aarhus 2005.
[10] Thompson Fred, 'en spaltet national-identitet' Arkitekten #25 1996, s 14-21.

us. We were looking for a structure that would express playfulness, movement and lightness. I suggested that we could fold the plate two ways like in a 'Le Klint lamp'. [11]

Copenhagen at that period was a well-preserved classic compact city with garden suburbs and, perhaps due to the influence of the Klintian School very few of the vast modernist projects and plans had been realised. Instead, the contextual strategies from the English tradition of the Picturesque were reinterpreted through Arts & Crafts[12] and the Klintian School. Talented landscape architects, such as Edith and Ole Nørgaard and Jørn Palle Schmidt and Agnete Muusfeldt, took further the strategies of enhancing already present characteristics in the landscape, so that their work seems self-grown and natural, though still modern. Ruskin's notion of 'fidelity to place' or to the genius loci, was a central concern for this group of Danish architects though they never used these expressions. Poul Erik Skriver, editor of the Danish Architectural magazine, 'Arkitekten', wrote that site and house should be one: a house should blend with the surroundings[13]. From this period, we even see modern versions of thatched houses. The choice of natural 'vernacular' materials, asymmetry, and integrated parallel working with both landscape and house, produced the 'Golden Age of Danish Modernism'.
The Virum Sports Hall was designed in this architectural context.

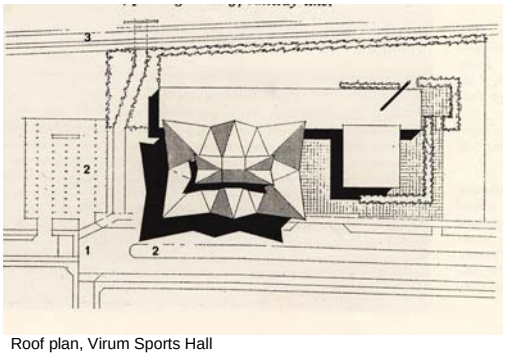
Cross Section Virum Sports Hall

Ideal Spatial Structures – the Principle of the Folded Plate
The innovative structural engineering of the Sports Hall could be categorised as a folded plate structure. The great roof enclosing the main space is the all-encompassing signature of the complex.
The Sports Hall's folded plate structure belongs to the stock of what civil engineer, Curt Siegel, in his classic book 'Strukturformen'[14] called 'räumliche tragwerke', spatial structures. The majority of structures today and in the past are considered as a combination of separate parts. The engineer calculates one beam at the time, though in reality, of course, the engineer knows that the parts 'work together' to carry the load. He views structure in this way for pragmatic reasons – just to keep it simple. But examples like ruins left by war show unbelievable and apparently impossible structures produced out of plain vernacular structures, showing that the way the load was actually carried was much more complex than perceived by the constructors.[15]

Jørgen Nielsen worked all his life as professor of structural engineering at a beaux arts academy, which gave him the unusual opportunity, at least for engineers, of participating in trips to study the architecture of ancient Rome and Greece. This resulted in very interesting analyses of ruins such as the vaults of Apollodorus[16], which are still standing seemingly despite natural laws. Of course Jørgen Nielsen's complex analyses take advantage of the concept of spatial structure, and his puzzlement over these ruins may have sharpened his view and the development of his theories of 'moment field method', a theory and calculation method for working with spatial structures. [17]
Spatial structures are not divided into separate parts calculated independently. Apart form the historic cupola, which is also a 'spatial structure', they form a group of structures evolved during the first three decades of the 20th century and based on new theories and working methods developed by engineers in this period. [18]The concrete hyper-shells of F. Candela are probably the best known, though K. Wachsmann's famous steel tube hangar and of course R. Buckminster Fuller's tensegrity domes were only possible because they were calculated as total entities and not one part at a time. Folded plate structures are

[11] Interview, Finn Monies Aug. 2006
[12] A relation documented eg by: Watkin, The English Vision 1982. p. 131.+ p. 132 , Hussey Christopher, Studies in a point of view, London 1927 p. 229-230
[13] Skriver Poul Erik *Huset og grunden* Kbh. 1963 p5-6
[14] Siegel Curt, Strukturformen der modernen Architektur', Münschen1960 p. 177
[15] Ibid, p. 178
[16] Eg in Mercato de Traiano
[17] Nielsen, Jørgen 'Ide Kraft Form, Copenhagen 1998 s. 49-58 ('Apollodorus' Apsidehvælv)'.
[18] Cowan, Henry J., 'Architectural Structures' N.Y. 1976. p. 30.

probably the least commonly used of this stock of structures. And the Virum Sports Hall is a very special interpretation of this structural principle, as we shall see.
But what spatial structures have in common is the notion of equilibrium, first of all between tension and compression (and seeking to reduce bending moments). Of course, it is the notion of viewing the structure as one whole unit that allows the large scale work with equilibrium, because compression in one part of the structure can be met with tension in another part, levelling out the forces and thereby reducing the total amount of stress. This again allows the use of less construction material, and reducing the weight of the structure as a whole allows greater spans, etc. A good circle starts and it is not difficult to understand the enormous advantage of looking at structure in this way.
The problematic aspect is, of course, to perform such extremely complicated calculations, which was why structures were calculated as separate parts in the first place. But Jørgen Nielsen, Nervi, Candela, Torroja, etc. were helped by the 'graphostatic' method commonly in use in the late 19th century and into the 20th.[19] Instead of numerical calculations, the German engineer Karl Culmann (1821-1881) developed a graphical tool. By means of descriptive geometry (developed for engineering use by Gaspard Monge, 1746-1818) graphostatics makes it possible to draw how forces run in the structure as a whole. It is a tool giving exactly the kind of total overview needed for handling spatial structures.
Jørgen Nielsen (almost) belonged to this generation and was used to graphostatics from his youth. He explained how he could visualise how forces would run in the folded plate structure at Virum using Cullmann's methods.[20] A theory for shell spatial structures was initiated (or assembled) by Danish civil engineer, Prof. KW Johansen. Felix Candela is said to have come across KW Johansen's article and to have translated it by means of a Danish-Spanish dictionary.[21]



Roof plan, Virum Sports Hall

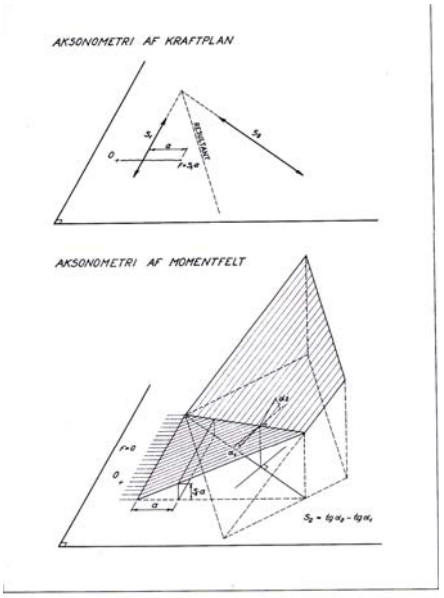


Fig. 1. Momentfelt for stangkræfter. Momentfeltet danner en knækket flade med knæk over stangkræfterne. Ændringen i hældningskoefficient vinkelret på en stang er lig stangkræften. • *Moment field of forces in members. The moment field is composed of plane surfaces intersecting over the forces in the members. The change in the slope at right angles to a member is equal to the force in this member.*
'Grafostatical' drawings from Jørgen Nielsens Article, 1964

The Theory of Moment Fields
K. W. Johansen's theories were also important for Jørgen Nielsen's theory of moment fields. KW Johansen applied Airy's stress function (a mathematical expression for equilibrium) to the calculation of shells, by conceptually segmenting the shell in positive and negative stress in 3 dimensions, explained both mathematically and graphically (diagrams), [22] with a view to achieving the resolution of bending moments and thereby a statically determinate structure. Jørgen Nielsen took this method further by giving even more 'visibility' to the extremely abstract notion of stress function and thereby developing an even more useable tool for calculation of spatial structures: the notion of the moment field and its graphical expression. *Any moment field which is built up of plane surfaces over the space frame polygons, and which satisfies the*

[19] Cornell, Elias, Bygnadstekniken, Stockholm 1997, p 218-220.
[20] Authors interview with Jørgen Nielsen, June 2006
[21] Lund Morten, 'Vilhelm Laurtizen, en moderne arkitekt' Copenhagen 1994, p.290. Morten Lund got this information form architect Nils Fagerholt in an interview made in 1993. Nils Fagerholt interviewed Felix Candela in Mexico 1960.
[22] Johansen, K.W. 'Bøjningsfri spændingstilstande i skaller', Bygningstatiske Meddelelser 9.årg. 1937 p. 61-68

external loads, corresponds to a state of equilibrium in the structure. Therefore the forces in the members can be measured simply as differences in slopes between the planes constituting the moment field. [23]
This means that Jørgen Nielsen could perceive the folded plate structure at Virum as a kind of lattice, where he only needed to calculate the moment fields of intersections (ridges and furrows) in order to work out the horizontal stress. The only thing left to find out is the equation for vertical projections. The vertical part is determined by taking the horizontal and multiplying by their respective slopes.[24] The principle applied for each intersection can be used for the whole structure as such. T*he total moment field of the structure must have the same values at the corner points as the space lattice formed by the ridge lines of the prismatic shell structure when the loads are referred to the joints*.[25]
The complexity is reduced considerably compared to KW Johansen's method of using a visual 3-dimensional strategy derived from Cullmann. Where KW Johansen used diagrams as a sort of pedagogical means to explain the equations, Jørgen Nielsens method *produces visual, spatial figures consisting of moment field planes of the outer and inner parts of the structure from which all stress resultants can be read immediately.*[26]

Interior/Exterior
The Virum structure is more complex than a simple folded plate structure because of the two-way folding (like in a Le Klint lamp)[27] and because of the rectangular lantern placed centrally. The vertical load is distributed uniformly along the two symmetry lines[28], but diagonally some bending moments occur. Here pre stressing was used, in line with what KW Johansen suggested for these kinds of problems.[29] It was always part of the design to have tension at this spot so in the 4 corners of the structure tension cables go to anchors underground. And it is actually possible to get the impression – viewed from the exterior – of the lantern hanging, carried by cables from each corner.
But viewed from the interior, it is the 6 columns under some of the 'furrows' that take the focus, leaving the impression that the lantern is pushing down, producing compression load. The folded structure can then for some moments seem like a cantilevered structure spreading from the columns, carrying the lantern.
The carefully worked out equilibrium between tension and compression is perceivable and defines the spatial qualities of the building, the play of forces constantly changing as the viewer moves around the building.

Inside we find the extremely high level of craftsmanship and finish characteristic of 'the Golden Age of Danish Modernism', with Arts and Crafts ideals made modern. For the floor of the Sports Hall Finn Monies chose a panga-panga hardwood floor, looking new even today. Oakwood panels on the walls mediate between the dark floor and the pale acoustic ceiling (also original and in good condition today).[30] In the dressing room part of the building, custom-made cabinets in Oregon pine line the 30-meter corridor to one side and cabinet-like carpentry completes the ceiling with integrated wooden cladding and skylights. The combined restaurant and hall has a ceramic floor and a mural by artist, Inger Hamann. [31]

[23] Nielsen Jørgen, Nordisk Betong # 4, 1964
[24] Ibid. P. 469
[25] Ibid. P. 484
[26] Nielsen, Jørgen, 'Momentfeltmetoden for rammer', Bygningstatiske Meddelelser' Copenhagen, vol 42,1971, no.2, p 75-99
[27] Interview with Finn Monies July 2006. Monies suggested to Jørgen Nielsen, that the folding should be like a 'Le Klint' Lamp.
[28], uniformly' in this relation means that the load is anti metric; In two corners (diagonally facing each other) positive moment occurs while the two other corners have negative moment.
[29] Johansen K.W. opus cit. p. 70.
[30] As explaind in article in 'Arkitektur DK' #2 1969 p. 73
[31] The mural was a donation from the craftsmen and technicians involved in the construction of the building., interview Finn Monies July 2006

Virum Sports hall, facing the railway tracks

The restaurants projecting roof as mediating scale

Virum Sports Hall The ‘garden fench’ façade of the entrance and the reversed ceramic tiles of the base.

Contextual strategies of Virum Sports Hall

The exterior is extraordinary in every meaning of the word, although the Sports Hall still seems natural in the quiet suburban surroundings. This paradox deserves our attention. The initial, contextual strategy of Finn Monies was that the Sports Hall should have two façades. Along the western part of the site there is a busy railway line. The 20,000 people passing by at high speed every day here should be able to see the building as a simple sign, making it a point of reference in their journey. To the east the site faces a residential area in the suburb of Virum. Here the intention was to create a small square as an entrance area.[32]

When seen from the railway the Sports Hall’s huge folded plate structure catches the eye, served to the viewer on a plain wall, with horizontal window strips facing the tracks. It was always thought as the ‘big public’ façade addressing Copenhagen as such. Today this façade is even more different from the residential

[32] ‘Arkitektur DK’ #2 1969 p. 73

eastern façade because of the massive graffiti paintings, which are left as they are by the Sports Hall's management though the grass is neatly mowed and the windowsills well maintained. It seems in correspondence with the architectural intention that this should be a kind of graffiti gallery. The spatial structure can take it; it looks appealing.
The entrance façade on the other hand has a more subtle and difficult task to perform; to mediate between the small scale suburb and the spatial structure. The road leading to the Sports Hall is lined with 3 rows of plane trees. The parking is in the middle part of the road under the central row of trees. Yew hedges spread at right angles to the road on a strip of lawn leading from the station. The first glimpse of the Sports Hall coming up the hill from the station is seen through plane leaves with low yew hedges in the foreground. The real scale of the eye catching folded plate structure is veiled by the Sports Hall's restaurant pavilion performing the classic task of mediating between foreground and background with a middle scale. Its huge horizontal roof projecting 1m in front of the glass façade performs as a proportional stepping stone even when seen from close. The small entrance square has a quiet gardenlike quality with shrubbery in the middle. The tactile qualities of the walls facing the square underline this: the characteristic entrance partita with vertical black painted posts reminiscent of a garden fence is related to similar posts in the Louisiana Museum's 'garden corridors'.
The lower part of the Sports Hall is clad with rough ceramic tiles, brought about by reversing the tiles, so the rough side normally used for fixing the tile to the wall is facing the square. In this way another classic contextual strategy is used: rustication of the lower part of the building and gradual refinement with the rooftop lantern as the final artefact.

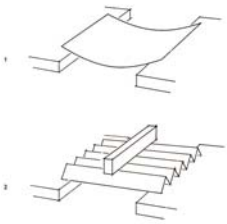
Apart from the interpretation of classic strategies involved (including the initial one of the two-sided complex), another set of ideas is used for integrating the ideal structure with its setting. In fact, it has to do with the very choice of the folded plate principle and becomes apparent when comparing the Virum Sports Hall to the Kildeskov Swimming Pool built 5 years later. The Kildeskov Pool was built in a small bit of woodland left over in a residential area. Agnete Muusfeldt, the landscape architect, had the idea of maintaining the forest quality. This impossible task was taken as a challenge by engineer Christian Osterfeldt and architects Karen & Ebbe Clemmensen, who produced an extraordinary tree-like spatial structure, gradually growing up from a dark masonry base. This building also deserves attention for its unique strategy for integrating ideal structures with the surroundings, though a description would be too extensive for this paper.
In Virum, gable-roofed dwellings – both blocks and single-family houses – surround the Sports Hall. The choice of the structural principle of the folded plate structure on a meta scale relates to these characteristic shapes in the neighbourhood.

Future Spatial Structures?
Spatial structures are not so commonly used in building anymore. Christian Meyer did some interesting research into why interest in e.g. hyper shells seems to have disappeared. Their answer was that while the development in materials and casting moulds make hyper shells even more attractive, they are out of fashion with architects.[33] One reason that they are out of fashion with architects could be because of the problem of integrating the odd shapes in urban or landscape settings. But ideal structures, defined as structures that are shaped according to engineering principles and natural science, can still meet this demand and perform well contextually (in every aspect of the word) as we have seen.
One might get the idea by looking at new architecture today that the odd shape of ideal structures/spatial structures is not exactly the problem. On the contrary, UN studio, Zaha Hadid, and many other studios use computer technology to work with shapes of extremely complex geometry, and the continuous character of the structures has some resemblance to spatial structures as a category. And one of their reasons for doing this is contextual. When, for instance,. UN studio punctuates, stretches, twists, etc. the architectural figure of e.g. Arnhem Central, it is in order to create one continuous landscape that can grasp, mirror and contrast heterogeneous, ill-defined places.[34] The postulate is that the shapes come from the architect being a 'public scientist'. *Reformulating the architectural project as a seamless constellation of infrastructure, urban planning, construction, programme mix and public policy.* [35]The multidisciplinary approach has resulted in engineering projects such as the Erasmus Bridge.

[33] Meyer Chrstian, Michael H. Sheer, Concrete International. Vol 27 #10 2005, p.43-51.
[34] Architecture and Urbanism #6:405 2004 p.89
[35] Ibid: Berkel Ben van, Bos Caroline: The new, new concept of the architect – revised, recharged now more hopeful than ever', Architecture and Urbanism #6:405 2004, p.98

The underlying postulate is that by working with a non-linear and non-deterministic relationship between diagrams and concrete constructions, the structure will be able to respond to complex contextual situations. [36]

The result is architecture that is loaded with natural science[37] but no regard for the premises of the natural science and engineering, as the cost of the structures show.
What the structures of UN studio and Zaha Hadid throw out is the ideal notion of economy of structures. Curt Siegel has pinpointed it in his book, 'Strukturformen': *with the integration of technical principles in the field of aesthetics the thought of economy gets a new meaning. It has nothing to do with money. Economy is a spiritual principle, a kind of moral for structures which gets the highest worth (both in spiritual and aesthetical sense) by striving for the optimal performance.* [38] What engineers failed to do was to look at their structures from this conceptual point of view, which is needed in order to communicate structural principles to architects that work on a conceptual level. Instead companies like Arup specialise in 'translating' blobs into buildable geometry that looks non-Euclidian (or topological) and placing cables and armament that allows shapes to look as though they work against the laws of nature.[39] Compared to this Finn Monies and Jørgen Nielsen looked for a geometry that would reduce bending moments to a minimum and at the same time comply with a set of complex contextual strategies. Presently the ideas and knowledge of structural engineering in its own right – as for instance manifest in spatial structures – is not the focus for architects, so their architectural potential is still to a large extent unfulfilled.



From 'Strukturformen', Curt Siegel, The principle of the folded Plate

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[36] Lynn, Greg; 'Folds, Bodies & Blobs'; Forms of expression: the proto-functional potential of diagrams in architectural design, Bruxelles 1998, p. 224,
[37] Gregory, Rob,: 'Ancient and Modern - while the physical and spatial fluidity of concrete is no new thing, computer modelling techniques and advances in chemical science are allowing the humble concrete mould to produce exciting new forms of expression'. 'Architectural Review', January 2004, p.54
[38] Siegel Curt opus cit.: p 7, autors translation from German: *Mit der Einbeziehung technischer Gesetzmässigkeiten in die ästhetischen Werteskalen gewinnt das ökonomische Denken erhöhte Bedeutung. Das hat mit billig im Sinne von preiswert nivhts zu tun, ôkonomie ist hier ein geistiges Prinzip, eine Art umfassendes Moralgesetz für das Gestalten, das höchste Leistung (einschliesslich geistiger und ästhetishcer Werte) bei geringstem Aufwand erstrebt.*
[39] Balmond, Cecil: New structure and the Informal, Assemblage #33 1997, p. 46-57