From Typology to Topology: Social, Spatial, and Structural

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Abstract:

Structural engineering science radically transformed its ontology and methodology from a typological to a topological paradigm. This implies a radical reset of the categories that guide engineering practice. The modern forms of engineering rationality based on system types are now exposed as inefficient while the rationality of older structural forms based on slowly evolved traditions is now revealed by the new paradigm. These forms – like the Gothic Cathedrals - often offer higher degrees of efficiency that were not verifiable via calculations before the advent of the computational revolution in engineering science. Beyond this revelation and recuperation of premodern more differentiated and integrated solutions we witness the proliferation of radically new forms that the new paradigm makes possible. This radical expansion of structural possibilities – mirroring the endless forms of nature - is congenial with the requirements of contemporary architectural design where a much higher degree of versatility is required to meet the challenges of a much more complex society.

Keywords:

Paradigm shift, typology, topology, optimization, engineering rationality, interdisciplinarity, congeniality, finite element analysis, redundancy, tectonism, tectonic articulation, parametricism

We are living in an increasingly dynamic and complex world where social institutions, social types and identities proliferate, hybridize and indeed seem to blend into each other, into a continuously differentiated social texture. Stable stereo-types dissolve and fixed hierarchies have everywhere given way to fluid networks, both in our private and our working lives. We might summarize this by saying that our modern social typology has given way to a post-modern condition of social *topology*[i].

This new fluid societal condition has a material base: the fourth industrial revolution[ii] with its ever more pervasive use of digital computing power crunching through ever bigger data sets in the quest for ever more subtly tailored adaptive product and service optimizations. This new social life process is also demanding a new congenial built environment, equally differentiated and fluid; and naturally this new built environment can be delivered only via upgraded architectural and engineering disciplines that are equally empowered by the new digital computing powers. The new condition implies that each new construction project is characterized by both complexity and novelty. Routine solutions are out of the question. R&D is now always involved. This implies a closer collaboration between the various contributors: developers, architects and engineers.

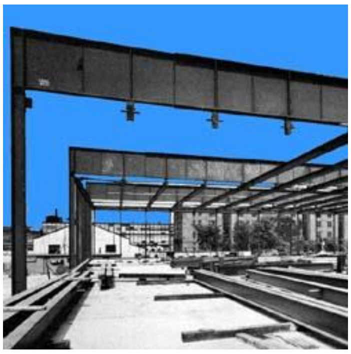
Intense Collaboration and Strict Distinction between Architecture and Engineering

There is no doubt that progress with continuously increasing performance - in general as well as in relation to the built environment - implies the need for an intensified specialisation and collaboration of the specialists in interdisciplinary expert teams. However, interdisciplinary work does not imply the dissolution of disciplinary boundaries. While individual careers might migrate across disciplinary boundaries, effective interdisciplinarity, demands that at any time the different competencies that are expected to contribute to the overall success of the project are clearly demarcated. The premise of our contribution here is thus a double thesis that implies both the strictest demarcation and the closest collaboration between architecture and engineering as preconditions for the productive advancement of the built environment. The underlying division of labour might be posited as follows: Architecture is responsible for the built environment’s social performance. Engineering is responsible for the built environment’s technical performance. Technical performance is a basic precondition of social performance. In this sense engineering might be argued to be primary. Social performance is the goal. In this sense architecture might be argued to be primary. Thus the relation cannot be brought into a hierarchy. Rather it is a relation of mutual dependency and dialectical advancement. Architectural goals must be defined within a technically delimited space of possibilities. Engineering research and development thus expands the universe of possibilities that constraints architectural invention. However, it cannot be taken for granted that engineering research and development expands the universe of possibilities in relevant, desired directions without being prompted and inspired by architectural goals. In turn architectural goals and inventions might be prompted and inspired by recent engineering advances. The two disciplines co-evolve in mutual adaptation. Evidence of this can be found in the congeniality between the architectural avant-garde style of parametricism and structural engineering's contemporary capacity to model and evolve optimizing, smoothly differentiated structures. However, we have to reflect that for us architects these differentiated structures enter our considerations as just another set of compositional elements in our quest to differentiate the spatial scene in accordance with the differentiation of social situations. Congeniality does not imply the conflation of concerns and competencies.

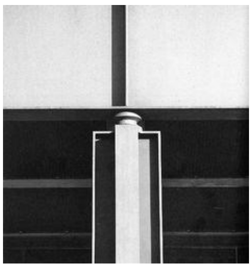
Structural Fluidity – From Typology to Topology in Structural Engineering

The digital revolution that brought a series of powerful new design tools into architecture has also provided structural engineering with new tools to analyse and calculate structures in the manner that is congenial to the architectural ambition towards parametric variability that has been unleashed by the new digital design tools. Traditional and 20th Century modern architecture was a game of assembling simple platonic forms like cuboids, cylinders, spheres, and pyramids. The key characteristic of contemporary architecture that challenges engineering is the pursuit of complex and continuously changing forms. Such fluid forms can no longer be analysed by means of decomposing them into discreet elements establishing clear cut structural systems. This is significant because it challenges structural engineering with respect to its most basic elements and concepts.
Classical modern structural engineering – in distinction to contemporary engineering - relies on the ability to decompose any structure into clear and independent structural sub-systems and elemental members. Each sub-system adheres to standard concepts like column, beam, cantilever, portal frame, arch, slab, barrel vault, dome etc. This typology was taken to be definitive. Each of these concepts is

characterised by a clearly typified geometric schema with its attendant configuration of loads, supports and forces. Each can be further characterized by more detailed system choices, i.e. a beam might be articulated as truss, vierendeel beam or box beam etc. Within each simple subsystem the active forces can be easily ascertained, and great care is taken to control the transference of forces from subsystem to subsystem by the precise articulation of the joints that only transmit a particular, well defined force. The overall arrangement of forces can then be traced step by step. This strategy of clear and distinct decomposition sacrifices efficiency and redundancy for analytical clarity and tractability. This strategy of decomposition is then aligned with the strategy of uniformity within each system, eschewing differentiation. Both decomposition and uniformity are strategies for the reduction of complexity that recognises the narrow computational capacity of the pre-digital era. Uniformity recognizes also the industrial fabrication system of the Fordist era.

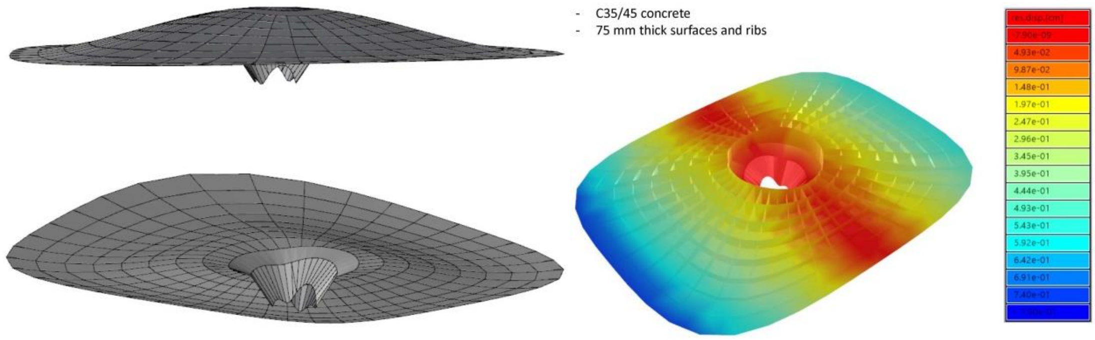
Mies van der Rohe, Crown Hall, Illinois Institute of Technology, Chicago 1956. The primary structure here uses the portal frame as distinct structural system type. A sequence of our large-span portal frames - bound together by secondary beams – make up the structure.

Mies van der Rohe, National Gallery, Berlin 1968. The structure is a beam grid on 8 columns with hinge joints. In both examples the modern structural principles are clearly in evidence: Distinct system type, uniformity, decomposition into discrete elements with controlled load/force transmission at the joints. Yet another aspect of modern engineering becomes evident here: These principles owe their historical rationality as much to the Fordist fabrication logic of mechanical mass reproduction of standardized industrial elements like the I-beam.

In contrast with this modern typological approach contemporary engineering has become topological and can thus better serve the new architectural style that aims to create spaces which are morphing different spatial sections into a seamlessly differentiated continuum that resists any decomposition into discrete spaces that could be conveniently structured by discrete structural systems. In traditional structures the ability to analyse and calculate the behaviour of the structure is premised upon the purity of structural type and the severing of all redundant connections. However, conceptually distinct structural system types - beam vs arch etc. – are disappearing from engineering due to the new modelling techniques like Finite Element Analysis. We thus witness a radical conceptual shift - a paradigm shift – within engineering. This is also an ontological shift as it revolutionises the most basic entities that constitute a structure. I would like to call this paradigm shift the shift from typology to topology. It is at the same time a conceptual shift from parts to particles with respect to the mode of decomposition for calculation. This shift in structural engineering has not been triggered by the new architectural style but rather follows from the internal logic of structural science in the pursuit of structural optimization, in combination with the computational empowerment that makes this pursuit feasible.

A very similar but initially independent shift has also transformed architecture: the pursuit of higher levels of variation and complexity in response to the new societal conditions, again in combination with the computational empowerment that makes this pursuit feasible.[iii] It is precisely the idea of typology – the thinking in clearly defined spatial types – that is also disappearing from contemporary architecture, especially within the movement and style of parametricism. In fact, “From Typology to Topology” was one of the early key slogans of the tendency within contemporary architecture that has since (since 2008) been termed parametricism. This implies that contemporary architecture escapes all modern engineering procedures. With new engineering tools like Finite Element Analysis, which break the structures into particles rather than into parts, the engineer is able to capture the ever shifting arrangement of forces. The universe of potential force patterns becomes boundless.



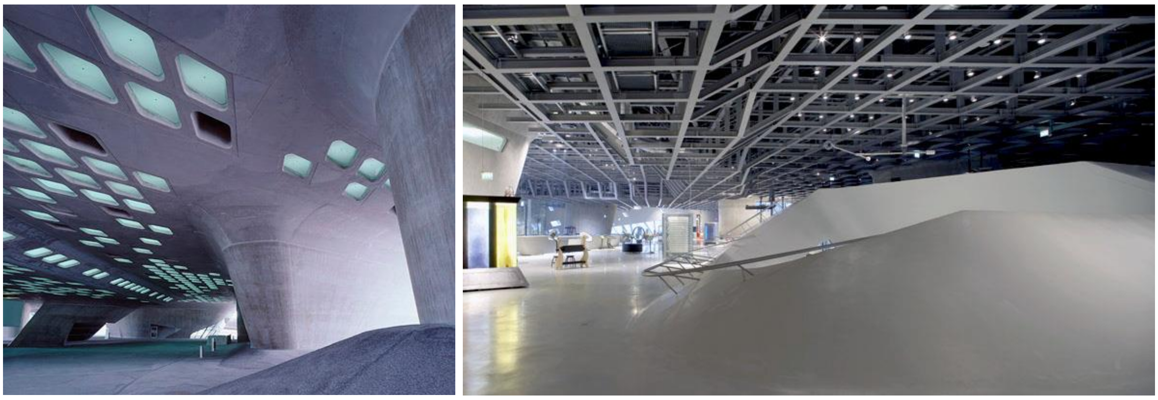
Zaha Hadid Architects, detail of villa project, undisclosed location. This mushroom-like roof structure follows no standard structural system type. The integration of structural analysis via Finite Element Analysis during the design process allows for structural feedback during the sculpting process. The stress distributions and deformational impact is modelled and becomes dependent upon the differentiated sectional profile. This is a first step towards optimization. Here structural calculation is not reduced to identify critical points that determine the dimension of a priori forms but all points become potentially “critical” points.

The mushroom roof shown here is similar to (but more complex) than Felix Candela’s concrete umbrella roofs. What Candela achieved via empirical test series, namely an optimized thickness distribution, can now be computed via Finite Element Analysis.[iv]

“From Parts to Particles” is another key slogan of contemporary architecture. Structural engineers can now analyse mixed, hybrid systems. A tool like Finite Element Analysis can also cope with dense, redundant interrelations of the parts of a structure. We no longer need to sever and isolate the structural components or subsystems. This means that we can harness the structural efficiency of an interconnected network, where parts work together rather than remaining independent from each other. The re-tooled engineer allows the structural forces to flow freely through the surfaces provided by the architect. This is the era of structural fluidity.

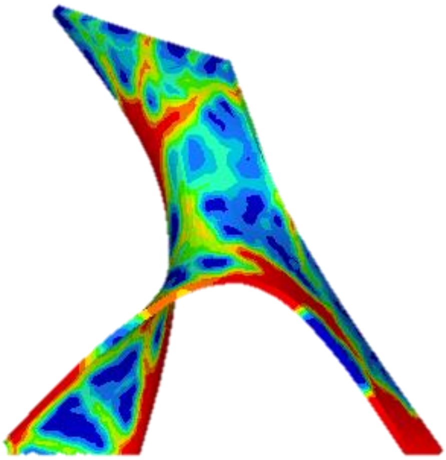
It thus becomes evident that the architectural style of parametricism is congenial with the most advanced (topologically based) engineering thinking, and indeed that parametricism is the only style that fully utilizes the new engineering intelligence.

I would like to cite Zaha Hadid Architects’ Phaeno Science Museum in Wolfsburg as an early example where the structural systems morph as much as the architectural forms. Here we can observe a mixture of spanning, cantilevering and vaulting within a waffle slab whereby spans and cantilevering dimensions are continuously changing. The cones flare into the waffle-slab rather than remaining discreet props that pick up their load at distinct points of contact. The space frame above is continuously differentiated whereby each member within the space frame has a different angle (the grid fans in two directions) so that each cell of the space frame has a different size. In a complimentary move each member has a different thickness and weight. Obviously, this nuanced optimisation can only be coped with by means of computers, both with respect to the calculation of forces as well as with respect to the handling of the complex geometry and manufacturing schedules.



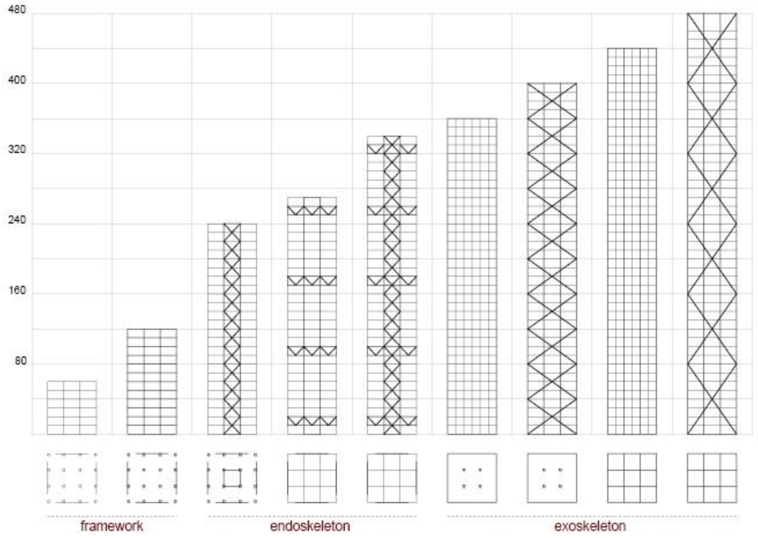
Zaha Hadid Architects, Phaeno Science Centre, Wolfsburg, Germany 2000-2005. Two structural systems – the waffle slab for the main floor and the vierendeel space-frame for the roof – are correlated via the structural cones as inhabitable mega-columns. Both systems are non-uniform subsystems, whereby the spaceframe is more subtly and extensively differentiated as the structural gridlines fan in both directions in adaptation to the trapezoidal global roof shape. Each cell of the vierendeel space-frame is thus unique and each member profile is individually sized according to the varied load conditions.

The next stage in structural design sophistication is the methodology of Topology Optimisation whereby the analytic capacity of Finite Element Analysis (FEM) is turned generative by means of being looped into an evolutionary algorithm.[v] The starting point is usually a simple block shape that connects loads with support points. The FEM reveals the stress distribution under the initial condition. Regions of low stress are then removed and the FEM is run once more on the new shape which is then again further eroded according to the new stress distribution etc. The initial bounding shape to which the topology optimisation algorithm is applied might itself be already a complex structurally optimized shape, like a shell form generated by the form-finding technique of mesh relaxation. As example might here serve an experimental structure created by Zaha Hadid Architects' CODE group.

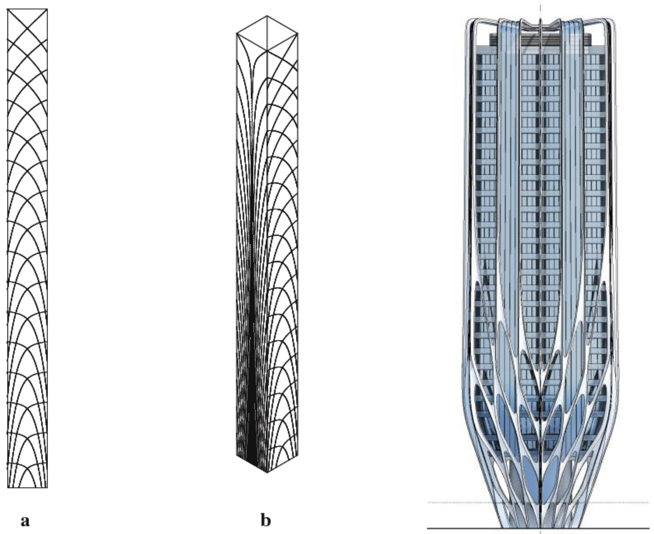



Zaha Hadid Architects' CODE group, experimental structure using a shell form as basis for the operation of the application of the topology optimization algorithm. Mexico City, 2013. Here the perforation pattern is a geometrically rationalized translation of the topology optimization.

As another recent example I would like to point to my AADRL parametric tower research. The ambition here is to replace the typological structural thinking in terms of a choice from a list of structural system types like core-type, out-rigger type and structural tube type with the idea of a tower structure that morphs across these types via a series of gradual 'phase changes'. Usually the tower structure is assumed to be a single, uniform system selected in accordance with the height or slenderness ratio, i.e. up to a certain height/slenderness the tower's stability can be secured by mere framing without core or bracing, while a somewhat higher tower would rely on a uniform core as stability system, while beyond this height/slenderness the outrigger system would be selected, and very tall/slender towers would be designed as a structural tube. The unquestioned presumption here is always that a tower should be conceived as a singular, uniform system without any systemic differentiation along the vertical axis of the tower. This a priori of systemic uniformity must be exposed as irrational. Its seeming rationality is the rationality of a bygone era. In former times a topology optimized and thus more complex and differentiated design was neither computable, nor buildable. However, now this default condition of system uniformity leads to a materially wasteful result. The accumulation of loads and moments towards the bottom of the tower suggests that bottom, middle and top of tower should be treated rather differently. This structural differentiation - whereby only in the lower parts of the tower the full outer surface is activated as structural tube and the upper areas might be structured rather differently – allows for a congenial programmatic differentiation. Neither programmatically, nor therefore architecturally, is uniformity any longer a desired default condition. This example once more demonstrates the congeniality of architectural parametricism and topological structural engineering.



These diagrams describe the modern structural principles for high-rise construction. Discrete and uniform system types – framework, endo-skeleton (outrigger system), exo-skeleton (structural tube system) – are selected according to a series of tower height thresholds. The underlying, unquestioned a priori stipulation or presumption here is the uniformity and discreteness of the systems.



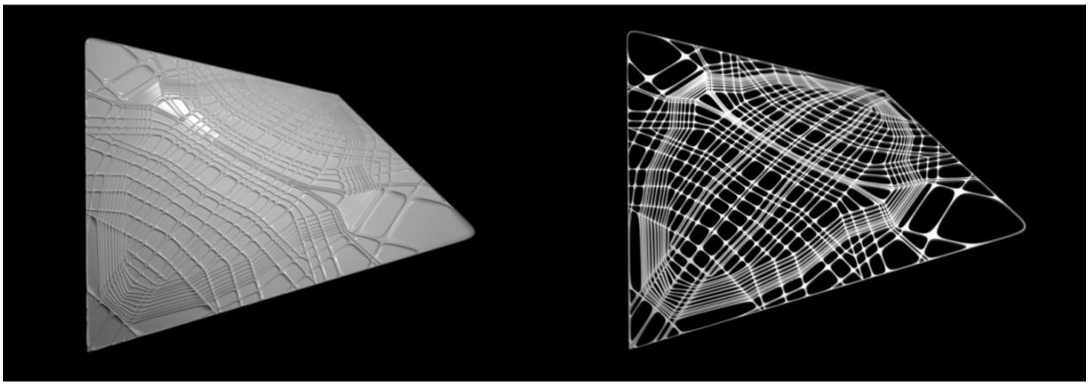
The a priori of modern engineering rationality is thus blind to the possibility of differentiating the tower structure along its vertical axis, either by gradually varying the pattern within a given system, for instance within the exo-skeleton, as displayed in diagram figures a and b, or by shifting and blending between different systems as shown in the elevation of ZHA’s residential tower scheme above, whereby what starts as a structural tube at the bottom transforms into a simpler framework structure. The possibility of such optimizing differentiations exposes the relative irrationality (structural inefficiency) of the modern structural rationality.

From Engineering Inspiration to Architectural Style: Tectonism[vi]

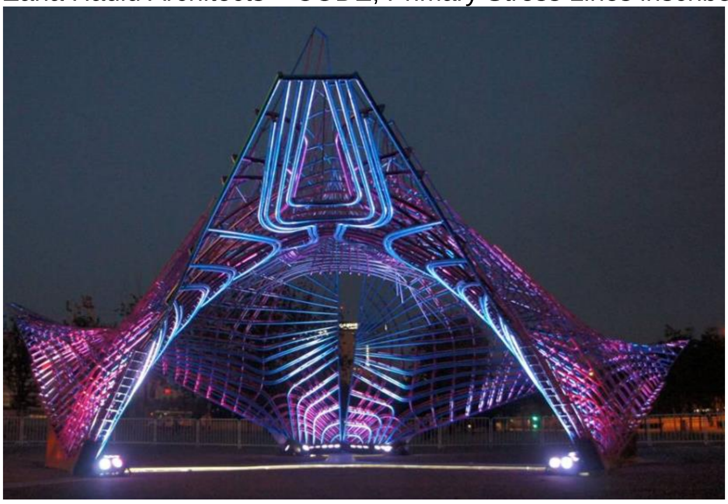
In recent years the protagonists of parametricism have increasingly engaged themselves with design methodologies inspired by the structural form finding techniques pioneered by Frei Otto. This is due to the availability of new digital physics engines that can simulate the material/structural form finding methods similar to Frei Otto's experiments with physical models. These new tools, mostly available as 'grasshopper' plug-ins, include RhinoVAULT for complex compression-only shells, 'kangaroo' to approximate shell or tensile structures, or analytic tools like 'Principle Stress Lines' analysis in 'Karamba' that can also be turned generative. Even structural topology optimisation tools have become readily available within the 'grasshopper' world. These tools deliver a quick structural form finding capacity to designers who are now able to explore these structurally disciplined, yet still sufficiently versatile, new design worlds and are able to gain an intuitive grasp of the structural logics at play. The same also starts to happen with environmental engineering parameters, and more recently also with respect to new fabrication constraints that can be encoded within the digital design tools. Various fabrication- and materially based geometry constraints can be embedded in generative design processes that are then set free to search the characteristic solution space delimited by the constraints. At ZHA CODE we are developing a lot of our own custom tools to model the particular constraints of particular fabrication processes.

The architects' use of these new design techniques involving engineering logics within the form-finding process does not imply that architects have become engineers, as it were re-unifying what the increasing specialisation of disciplines had severed starting in the 19th century. Architects are designers and their use of engineering-based form-finding tools is just their way to start the collaboration with engineers on the right foot. The structural intelligence behind those tools is the intelligence of the engineering sciences, and the final structural design and liability remains exclusively the engineers' responsibility. However, the new crop of architects pose as 'proto-engineers' who challenge and push the professional engineers to the frontier of their discipline, getting them involved in the new adventure of parametricism.

This new way of working has generated a new characteristic range of architectural morphologies. These morphologies are rather divers, due to the proliferating diversity of new materials, structural approaches and fabrication techniques. However, despite their proliferous variety, these new morphologies are recognisably of a peculiar, unmistakeable cast. They share a sense of organic intricacy. This should perhaps be not too surprising after all: all these works adhere to the general principles of parametricism and furthermore share this new additional commitment to computational form finding on the basis of engineering constraints. There is an unmistakeable unity that operates across this diversity. This recognisable formal unity, together with the unity of methodological principles and values justifies the positing of a stylistic variation of parametricism: Tectonism. The creations of tectonism are indeed as recognisable as the endless forms of nature are recognisable as such.



Zaha Hadid Architects – CODE, Primary Stress Lines inscribed and extruded onto a hypar shell form.



Zaha Hadid Architects CODE, Experimental Pavilion for Beijing Biennale 2013. Project is constituted by three hypar shells configured reminiscent of Felix Candela's Chapel of St. Vincent de Paul[vii] in Mexcio City. These shell forms were translated as layered grid shells whereby the gridlines are configured according to the computed primary stress lines. Stress densities were translated approximately via the number of grid-line layers: one, two or three layers. The system was visually further articulated via the differential colouring of the layers.

Tectonism implies the stylistic heightening of engineering- and fabrication-based form-finding and optimization processes. To be clear, despite its dependency on engineering logics, ‘tectonism’ is an *architectural* style. In fact, the concept of style(s) is a category that only makes sense within the discipline of architecture, as it necessarily refers to recognisable visual characteristics, albeit without thereby being reducible to matters of visual appearance.[viii] With respect to the engineering sciences the analogous term is paradigm (rather than style). So we can say that structural engineering’s recent topological paradigm is congenial to architecture’s style of parametricism, and in particular to its most recent manifestation: tectonism. Tectonism is the currently most prevalent and promising subsidiary style (sub-style) within the overarching paradigm and epochal style of parametricism. In retrospect we might distinguish tectonism from earlier phases of parmetricism like foldism and blobism[ix]. In contrast to these earlier sub-styles tectonism is embedding a series of technical rationalities that secure both greater efficiency as well as greater morphological rigour, while maintaining sufficient degrees of design freedom to address programmatic and contextual contingencies. Since the principles tectonism utilizes are inherently plural and open ended, this additional rigour comes along with additional tectonic variety and thereby offers a new reservoir of morphological physiognomies. This empowers designers to give a unique, recognisable identity to individual projects. Tectonism thus delivers much more expressive variety than foldism or blobism, without descending into arbitrary form invention.

While the overarching general design agenda remains parametricism’s pursuit of adaptive differentiation, tectonism pursues these with a much richer set of parametric drivers and constraints than earlier versions of parametricism. These drivers originate in sophisticated computationally empowered engineering logics that are now available to architects at early design stages via the structural form-finding tools mentioned above.

As a substyle of parametricism, tectonism partakes in the superior social functionality of parametricism with respect to the purposes and challenges posed by our fluid contemporary societal conditions. This superiority resides in the adaptive versatility of parametricism with respect to the complex programmatic mixes that need to be intricately woven into complex urban sites. This implies complex, irregular forms, interpenetrating spaces, multiple simultaneous contextual affiliations and gradual spatial transformations etc. This is what we might call spatial topology in the service of social topology.

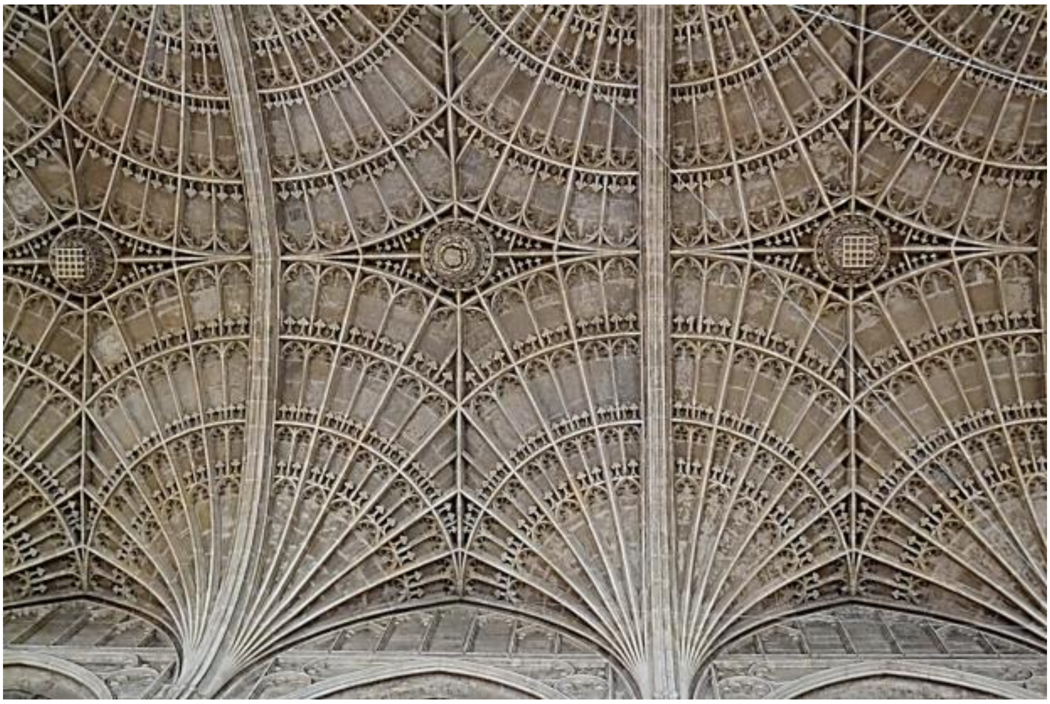
Parametricsim has the formal repertoires to shape and fit buildings so as to meet these complex requirements in ways that can also maintain legibility in the face of these unprecedented complexities. Tectonism can do all this and more: It can achieve all this while simultaneously meeting structural and environmental optimisation criteria. Furthermore, the morphologies that result from this pursuit gain – as if by serendipitous coincidence – additional visual legibility advantages. How is this possible? Well, it is the very rigor of the engineering logics that ruthlessly impose their selection criteria at every point across the overall form and that thus not only sponsor a formal unity across the project but also insure that the morphological variations are rule-based and thus predictable despite their complexity.

Tectonic Articulation – Making Engineering Logics Speak

The demarcation between architecture and engineering[x] rests on the distinction of the built environment's *social functioning* from its *technical functioning*. While the technical functioning considers the physical integrity, fabrication constraints, and physical performance of the building in relation to its users understood as physical-biological bodies, architecture must take into consideration that a building's social function. The social function of architecture is the ordering of social processes. This is achieved via spatial organisation. However, buildings function only by empowering users to find their way and each other within this organisation, i.e. the building must function as ordering and guiding *communicative frame*, and is thus functioning via its appearance and *legibility*. The core competency of architecture comprises thus, besides organisation, the crucial task of *articulation*. Legibility involves two aspects: the perceptual palpability and the semantic-informational charge. Accordingly the general task of articulation bifurcates into the two specific tasks of *phenomenological articulation* and *semiological articulation*[xi]. Both aspects need to guide the designer's decision making process in the context of the proliferating options that emerge from the engineering discourse. Semiological articulation presupposes a successful phenomenological articulation. Phenomenological articulation pursues the visual decomposition of the (increasingly complex) urban scene by making the relevant functional units (units of interaction) conspicuous. This concern with the visual decomposition of a complex composition motivates us at Zaha Hadid Architects to work with curves and curved surfaces. Shells, like blobs, remain traceable spatial units even if they start clustering, intersecting or fusing. The size of blobs or shells is communicated locally via the degree of their surface curvature. Inside versus outside are encoded as concave versus convex. Zones of overlap between such spaces clearly reveal their constitution. All these informational capacities enhance the inherent information richness and legibility of such compositions in contrast to orthogonal or cuboid systems. This is our *architectural* motivation to utilize shell structures. The structural efficiency of shell structures is of course very welcome too and implies that we do not have to fight with our structural engineers. However, the happy coincidence between structural and architectural motivations does not imply their conflation. Our architectural reasoning proceeds as follows: The perceptual identification of functional units and their interrelations is facilitated by the use of convex forms like shells. The use of convex (and concave) surfaces with various degrees of curvature gives useful orienting information. The use of structural form-finding logics disciplines the spatial morphologies in ways that are advantageous for the task of articulation, i.e. the task of elaborating a systematic spatial language. Semiological articulation can then map significant programmatic distinctions onto conspicuous morphological distinctions so that morphological differences indicate programmatic differences. The formal unity of a structural morphology range can be perceived and help users to recognize a programmatic unity across varied instantiations. Tectonic articulation – in the style of tectonism - is thus making engineering logics speak, via a designed visual code that selects a sub-set from the set of all conceivable structural morphologies and orchestrates these into a telling language. This language orients users as a navigation aid and tells them about the social offerings at hand. The built forms are not speaking about their structural performance (which is of no interest to users) but about their social purposes, and this communication facilitates these very purposes. Visual communication is exclusively the architects business, not the engineers. The engineer's business is to ensure, by means of the very same forms, their silent physical functioning. That's why the collaboration between architects and engineers has to be so close and congenial: Their very different responsibilities have to be met simultaneously, by the very same building forms. This collaboration between architects and engineers has to become especially intense within the style of tectonism. This style has the ambition to show, rather than to cover up and hide, the structural patterns, members, and details. These structural patterns, structural members and structural details become here articulate instruments of communication. They lead a double life, namely serving both physical-technical and cognitive-social functions.

Tectonic articulation is here thus proposed as the concept for the strategic articulatory utilization of the morphological differentiations that emerge from engineering logics like structural engineering, environmental engineering and façade engineering.

The history of architecture abounds with examples where architectural elements and features with technical functions become the object of articulatory or “ornamental” endeavours. However, we need to understand the instrumentality of ornament, i.e. we need to grasp ornament not in contrast to performance but as a special type of performance: communicative performance. A technically efficient morphology thus assumes also an articulatory, communicative function.



King’s College Chapel, Cambridge, 1446 – 1515, Gothic style fan vault. The variety and expressiveness of Gothic vaults clearly build upon structurally motivated patterns, and clearly heighten these patterns into an ornamental expressive state that communicates the special purpose and dignity of the space. These spaces are thus examples of what we are theorizing here as tectonic articulation.

The articulatory integration of the morphological consequences of technical requirements is always the more elegant solution than the attempt to fight and deny them by hiding or obfuscating them. This latter stance would require the invention of additional communicative features because social distinctions desire and require expression. However, the utilization of the initially technically motivated morphological features for the characterization of spaces is not only more economical but leads to a higher level of credibility of the communication because the morphological signifier is already an index rather than a merely arbitrary symbol. Thus, in the terminology of Charles Peirce, tectonic articulation transforms 'indexical signs' into 'symbolic signs'. This process too gives degrees of freedom to the designer in the selection of the indexical features that might be heightened and systematized to become elements of a semiological system of signification.[xii] In order for architects to pursue tectonic articulation they need to guide and orchestrate the engineering investigations and then select the engineering options that most suit their primary task, namely to fulfil the posed social functions via framing spatio-morphological communications. The adaptive differentiation of load bearing structures as well as the adaptive differentiation of volumes and envelopes according to the building's environmental performance (with respect to its exposure to sun, wind, rain etc.) as well as differentiations that stem from fabrication logics (e.g. tessellations) afford many opportunities for differential tectonic articulation. A thus lawfully differentiated built environment would be much more legible and navigable than the modernist, isotropic order of repetition. With the development of sophisticated computational design tools - both within architecture, within the engineering disciplines, and within the construction industry - the scope for nuanced tectonic articulation has much increased. The adaptation of structural morphologies to the force distribution within a structural system offers a fantastic opportunity for architectural articulation. In turn the more complex architectural orders proposed within contemporary architecture are reflected and potentially accentuated by sophisticated, adaptive structures. The realization of this potential requires an intensified collaboration between innovative architects, engineers and fabricators. Although there can be no doubt that architecture remains a discourse that is distinct from engineering and construction, a close collaboration with these discipline's, as well as the acquisition of reliable intuitions about their respective logics, are increasingly important conditions for the design of contemporary high performance environments. These environments will no longer be based on a typology of fixed stereo-types. These environments will be topological environments: socially, spatially and structurally.

Zaha Hadid Architects, design for a palace, undisclosed location. The Palace is designed as a cluster of shells. Both the external shell forms as well as the internal ribbing and perforation patterns are based on structural optimization algorithms. There are many ways to set up and compute the structural optimization and thus this design method delivers a rich variety of articulations that can then be instrumentalized for the expressive semiological articulation and characterisation of the various spaces like central entry lobbies, grand ballroom etc. Some of the ribbing patterns also function as internal orientation lines indicating primary entry points and spatial centre points.

End.

Notes:

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[i] The originally mathematical concept of topology implies gradual variation and transformation and its metaphorical expansion can thus serve us here as suggestive counter concept to the concept of typology.

[ii] Klaus Schwab, The Fourth Industrial Revolution, World Economic Forum, 2016

[iii] It becomes clear here that the invention and proliferation of computational information technology has been the decisive original underlying factor that has been and still is transforming not only architecture and engineering but all disciplines and arenas of professional and social life and thus underlies the global transformation of society.

[iv] POWELL DRAPER, MARIA E. MOREYRA GARLOCK and DAVID P. BILLINGTON, STRUCTURAL OPTIMIZATION OF FÉLIX CANDELA'S HYPAR UMBRELLA SHELLS, JOURNAL OF THE INTERNATIONAL ASSOCIATION FOR SHELL AND SPATIAL STRUCTURES: **J. IASS, 2010**

[v] X.Huang & Y.M.Xie, Evolutionary Topology Optimization of Continuum Structures – Methods and Applications, John Wiley and Sons, Chichester, UK, 2010

[vi] Patrik Schumacher, Tectonism in Architecture, Design and Fashion – Innovations in Digital Fabrication as Stylistic Drivers, Published in: AD 3D-Printed Body Architecture, guest-edited by Neil Leach & Behnaz Farahi, Architectural Design, Profile No 250, November/December 2017, 06/Vol 87/2017

[vii] Metcalfe, Ballard, A Structural Optimization of Félix Candela's Chapel of St. Vincent de Paul in Coyoacán, Mexico City, Princeton University Undergraduate Senior Theses, Civil and Environmental Engineering, 2014

[viii] For a full elabotation of the concept of architectural style(s) see: Patrik Schumacher, The Autopoiesis of Architecture, Vol.1: A New Framework for Architecture, John Wiley & Sons Ltd., London 2010, section 3.6 *Architectural Styles*

[ix] These older sub-styles are still practiced, just as during the era of Modernism the earlier white Bauhaus style continued in parallel with the later Brutalism.

[x] Patrik Schumacher, The Autopoiesis of Architecture, Vol.1: A New Framework for Architecture, John Wiley & Sons Ltd., London 2010, section 2.5 The Necessity of Demarcation

[xi] Patrik Schumacher, The Autopoiesis of Architecture, Vol.2: A New Agenda for Architecture, John Wiley & Sons Ltd., London 2012, section 6.6 The Phenomenological vs the Semiological Dimension of Architecture

[xii] A certain drawback here is that the articulatory repertoire is thereby somewhat constrained, so that this strategy might not succeed if the task of articulation is very complex.