The Architect and the Digital: Are We Entering an Era of Computational Empiricism?

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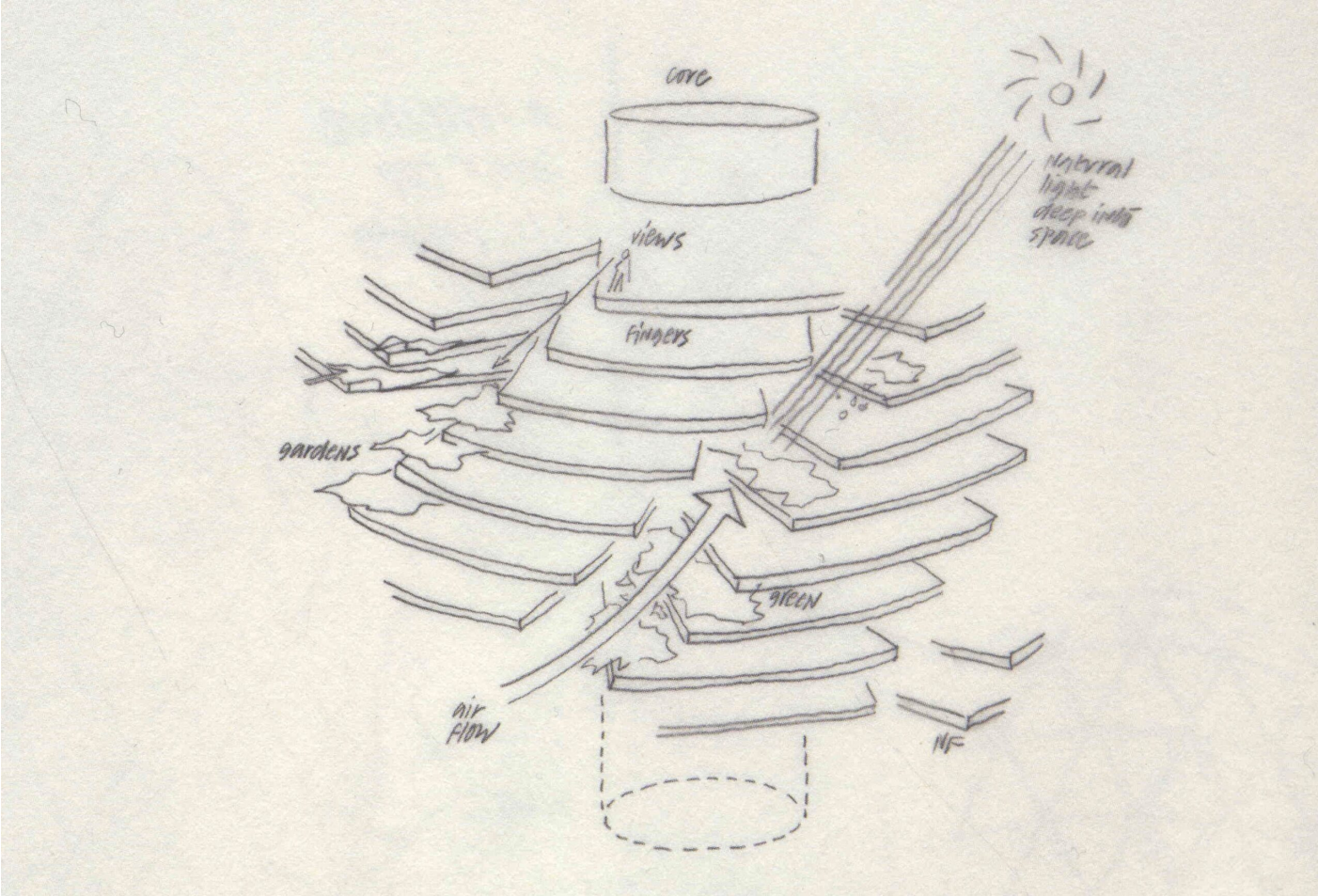

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The close integration of design with computational methods is not just transforming the relationships between architecture and engineering; it also contributes to reshaping modes of knowledge development.

This paper critically probes some issues related to this paradigm shift and its consequences on architectural practice and self-awareness, looking at the potential of typical teaching approaches facing the digital revolution. The authors, who teach an architectural design studio together, coming from different backgrounds and research fields, probe the topic according to their respective vantage points.

Over the last few decades, a design agency has developed of using digital tools for the interactive generation of solutions by dynamically linking analytic and/or synthetic techniques.

The analytic techniques make use of simulation, of the capability to forecast certain aspects of building performance. While in conventional practice simulation usually plays a consulting role in the later stages of the design process, in the new forms of agency it works as a generative device from the earlier phases.

The synthetic techniques address, on the other hand, more organic, para-biologic concepts – for instance "emergence, self-organization and form-finding" – looking for "benefits derived from redundancy and differentiation and the capability to sustain multiple simultaneous functions". [1]

Structures and their conception stand out as a part of architectural design where the digital impact shows its clearest consequences. Candela, Eiffel, Nervi and Torroja considered for instance that calculations have to go in parallel with intuitive understanding of the form: "The calculation of stresses", writes Torroja, "can only serve to check and to correct the sizes of the structural members as conceived and proposed by the intuition of the designer". [2] "In this fundamental phase of design", Nervi adds, "the complex formulas and calculation methods of higher mathematics do not serve. What are essential, however, are rough evaluations based on simplified formulas, or the ability to break down a complex system into several elementary ones". [3] At the time, the computational aspects were overridingly cumbersome; Frontón Recoletos required from Torroja one hundred and fifty-eight pages of calculations with approximate methods. Classical analytical procedures provided limited tools for simulation: "It was mandatory for the engineer to supplement his analyses with a great deal of judgment and intuition accumulated over years of experience. Empiricism played a great role in engineering design; while some general theories of mechanical behaviour were available, methods for applying them were still under development, and it was necessary to fall back upon approximation schemes and data taken from numerous tests and experiments". [4]

After the epoch of Nervi and Torroja, research and practice have been deeply influenced by the combined actions of computation toward a unifying approach to the different theories in mechanics, thanks to exponential performance improvements in the hardware, as well as achievements in symbolic and matrix languages, and discretization methods (e.g., boundary and finite elements methods) implemented in software. At present, the wide availability of computational methods and tools can produce numerical simulations out of complex forms, with the expectation of providing a certain degree of knowledge and understanding of mechanics, energetics, fluids, and acoustics. The compelling possibilities of boundary or finite element methods, plus finite difference or volume methods, has produced a shift from science of construction pioneers' awareness that not everything can be built, [5] to the "unprecedented morphology freedom" of the present. [6] Therefore, "We are limited in what we can build by what we are able to communicate. Many of the problems we now face", as Hugh Whitehead of Foster and Partners points out, "are problems of language rather than technology. The experience of Swiss Re established successful procedures for communicating design through a geometry method statement". [7]

“Parametric modelling”, Foster and Partners stated, “had a fundamental role in the design of the tower. The parametric 3D computer modelling process works like a conventional numerical spreadsheet. By storing the relationships between the various features of the design and treating these relationships like mathematical equations, it allows any element of the model to be changed and automatically regenerates the model in much the same way that a spreadsheet automatically recalculates any numerical changes. As such, the parametric model becomes a ‘living’ model – one that is constantly responsive to change – offering a degree of design flexibility not previously available. The same technology also allows curved surfaces to be ‘rationalized’ into flat panels, demystifying the structure and building components of highly complex geometric forms so they can be built economically and efficiently”. [8]

Of course, communication is here understood within a very specific part of the design process, mainly connected with fabrication issues and their optimisation, but it is a concept that involves many layered levels of meaning. [9] Curiously, this shift from the physical to the immaterial reminds us of the same step made by Leon Battista Alberti, who conceived design as a purely intellectual construct and was obsessed by its transmission from idea to built form without information decay. [10] Digital innovation promises to better connect the engineering process (focus on the object) with the wider reality (the architectural perspective), enabling design teams to deal with increasingly complex sets of variables. Freedom comes, however, with the disruption of the design toolbox, usually more defined by constraints than capabilities, so that the resulting wild fluctuations of effects seem increasingly disconnected from any cause. Design choices are therefore looking for multifaceted narrative support – and the “Gherkin”, with its combination of neo-functional-sustainable storytelling and metaphorical shape, turns out to be emblematic from this point of view too. [11]

Furthermore, extensive numerical simulations raise a question as to what extent they prove reliable, both because of their intrinsic functionality and the “black box” effect connected to the algorithmic devices. Those latter, especially in the latest applications of artificial intelligence such as neural networks, produce results through processes that remain obscure even to their designers, let alone less-aware users. Besides, the coupling of simulation with generative modelling through interactivity may not assist the designer in developing the understanding that, in several cases, (small) changes in the (coded) hypotheses can produce radically different solutions. Thus, the time spent in simulating alternatives can be more profitably spent working on different design hypotheses, and on architectural, technological and structural premises, perhaps with simpler computational models.

Are we entering an era of computational empiricism, as some authors maintain? [12]

Languages of innovation

Generative modelling, morphogenesis, parametric tooling, computational and performative design… all these apparatuses have brought methodological innovation into closer integration among different disciplines, bridging the gaps between fields. Modelling the project, the main common aim of this effort, has from the beginning leaned on logics and mathematics as a shared lingua franca. [13] Since the 1960s, applied mathematics has extended its applications through the formalisation process of information technology, which has developed the tools and the models beneficial for the purposes of science and technology. Information and communication technology puts into effect “the standardisation and automation of mathematical methods (and, as such, a reversal of the relationship of domination

between pure mathematics and applied mathematics and, more generally, between theory and engineering)". [14]

The redefinition of roles, between theories and techniques when applied to design, began in mathematics and physics with a metamorphosis of language, [15] with a shift towards symbolic languages that have gone beyond the mechanics of structures and the thermodynamics of buildings, subjecting it to automatic calculus, and finalising it in computation. [16] "Today, it is a widely held view that the advent of electronic computation has put an end to this semiempirical era of engineering technology: sophisticated mathematical models can now be constructed of some of the most complex physical phenomena and, given a sufficiently large computer budget, numerical results can be produced which are believed to give some indication of the response of the system under investigation". [17]

The straightforward capability to model and simulate projects, supported by the evidence of results, has given confidence in the emerging computational tools, highlighting the dualism between the desire to make these devices usable for a wide range of practitioners, in a variety of cases and contexts, and the exigency of grounding bases for deeper understanding within a reflective practice. Moreover, the very nature of using digital tools urges designers to face an increasing risk of becoming "alienated workers" who, in Marxian terms, neither own their means of production in actuality – software companies lease their products and protect them against unauthorised modifications – nor, above all, conceptually, since their complex machinery requires a specifically dedicated expertise. Therefore, within the many questions this paradigm shift is raising about the redefinition of theories and practices and their mutual relationship, a main concern regards educational content and approaches, in terms of their ability to provide useful knowledge to future practitioners and aid their impact on society. In the architectural design field – which traditionally crossbreeds arts, applied sciences, and humanities in order to fulfil a broad role of mediation between needs and desires – this means dealing with an already contradictory pedagogic landscape in which ideologically opposite approaches (namely method-oriented and case-oriented pedagogies) overlap.

The specific of architectural design teaching does not escape this tension between methodological ambitions, nurtured by modern thinking and its quest for rationalisation, and the interplay between generations, languages and attitudes involved by learning through examples – even with its paradoxical side effects. One would expect in fact that a "positive" (according to Christopher Alexander), rule-based training should yield more open-ended outcomes than the "negative", academic, disciplinary learning by copying. [18] But, on the one hand, the methodological approach implies an idea of linear control – towards optimisation and performance as well as in social and political terms – which reveals its origin in Enlightenment positivism. The Durandian apparatuses so widespread after World War II, with their proto-algorithmic design grammars, ended up accordingly with the reproduction of strict language genealogies. A similar trend seems to be emerging nowadays, in the convergence toward the same effective solutions in arts, sports, and whatever else, as a by-product of digital efficiency – which even the very technical camp is questioning. On the other hand, tinkering with the interpretation and application of examples makes possible the transmission of the many unspoken and unspeakable aspects connected to any learning endeavour. Getting closer to "good" examples – testing their potential according to specific situations – allows their inner quality to be grasped, reignited in different conditions, and finally transcended. Since *forgetting* requires something to be forgotten, Alexander is somehow right in framing this teaching attitude as "negative": ironically, imitation provides the learning experience through which personal voices can emerge and thrive.

Challenges ahead

Turpin Bannister considered that in “an age of science”, architects “abandoned the scientific approach as detrimental to the pure art of design. On even the simplest question they acquiesced to their engineer and so-called experts”. [19] The pervasive penetration of computation in design would probably have met Bannister’s approval. The consequences and methodological implications are so far-reaching that they raise questions: how must education deal with the increased role of interactive computation in architectural design? And, more generally, with techno-science, its languages and methodologies?

Architectural design still relies on a “political” attitude, and mediation between the “two cultures” [20] is a fundamental asset of its disciplinary approach. Even though the unity of knowledge has disappeared with the advent of modern science, as Alberto Pérez-Gómez stated, [21] we ideally aspire to become like renaissance polymaths, mastering state-of-the-art skills in the most disparate fields. But in the long time that separates us from Brunelleschi and Alberti, the amount of knowledge required by the different aspects of the practice, even those which are specifically architectural, has grown exponentially, and trying to get a minimum of mastery over it would demand a lifelong commitment and extraordinary personal qualities. Digital prostheses promise to close the gap between the desire for control over the many facets of the design process and the real possibility of achieving it. Some consequences of the augmented agency provided by new information and communication technologies are already evident in the overlapping occurring in the expanded field of the arts, with protagonists from different backgrounds – visual arts or cinema for instance – working as architects or curators and vice versa. [22] The power of the digital to virtually replace those “experts”, to whom, according to Turpin Bannister, architects outsource their own choices, seems to act therefore as an evolutionary agent against overspecialisation, confirming the advantage Bucky Fuller attributed to the architect as the last generalist. [23]

However, without understanding and manipulating what happens within the black box of the algorithm, we still face the risk of being “designed” by the tools we put our trust in, going on to accept a subordinate position. Speaking *machine*, as John Maeda has pointed out, [24] is becoming necessary in order to contribute innovatively to any design endeavour. The well-known Asian American researcher, designer, artist and executive comes from a coding background, later supplemented with the study and practice of design and arts (along with business administration). His educational path and personal achievements indicate that such an integration of expertise is possible and desirable, even though his logical-mathematical grounding is likely the reason he mostly works with the immaterial, exploring media design and the so-called experience economy. Architectural schools are therefore facing the issue of if, when, and how to introduce coding skills into their already super-crammed syllabuses – from which, very often, visual arts, philosophy, law, storytelling and other much needed approaches and competencies are absent. One can argue that coding would provide young professionals with expertise they could immediately use in the job market, enabling them to better interact with contemporary work environments. On the other hand, a deeper perspective shows how the “resistance” of architectural specificity produced exceptional results in revolutionary times: academic education acted for the Modern masters as both a set of past, inconsistent practices to overcome and a background that enhanced the quality of their new language.

Digitalisation looks like a further step along the process of the specialisation of knowledge, which unfolded hand-in-hand with the development of sciences, techniques, and their languages. Since the dawn of the modern age, architects have often tried to bring together a unified body of knowledge and

methodology; first around descriptive geometry, and then around geometry as a specific discipline which “gives form” to mathematics, statics and mechanics. “Geometry is the means, created by ourselves, whereby we perceive the external world and express the world within us. Geometry is the foundation”, Le Corbusier writes in the very first page of his *Urbanisme*, trying to keep pace with modernisation and establishing a new urban planning approach according to its supposed “exactitude”. [25] But while hard sciences and their technical application rely on regularity of results in stable experimental conditions, architects are still supposed to give different answers to the same question – or, more precisely, to always reframe architectural problems, questioning them in different ways.

Considering the volatility of the present situation, opening up and diversifying the educational offer seems a viable bet, more so than the attempt to formulate a difficult synthesis. Only by being exposed to the conflict between the selective, deterministic optimisation promise of code-wise design, and the dissipative, proliferating, unpredictable interpretation of cases can architects find their own, personal way to resolve it.

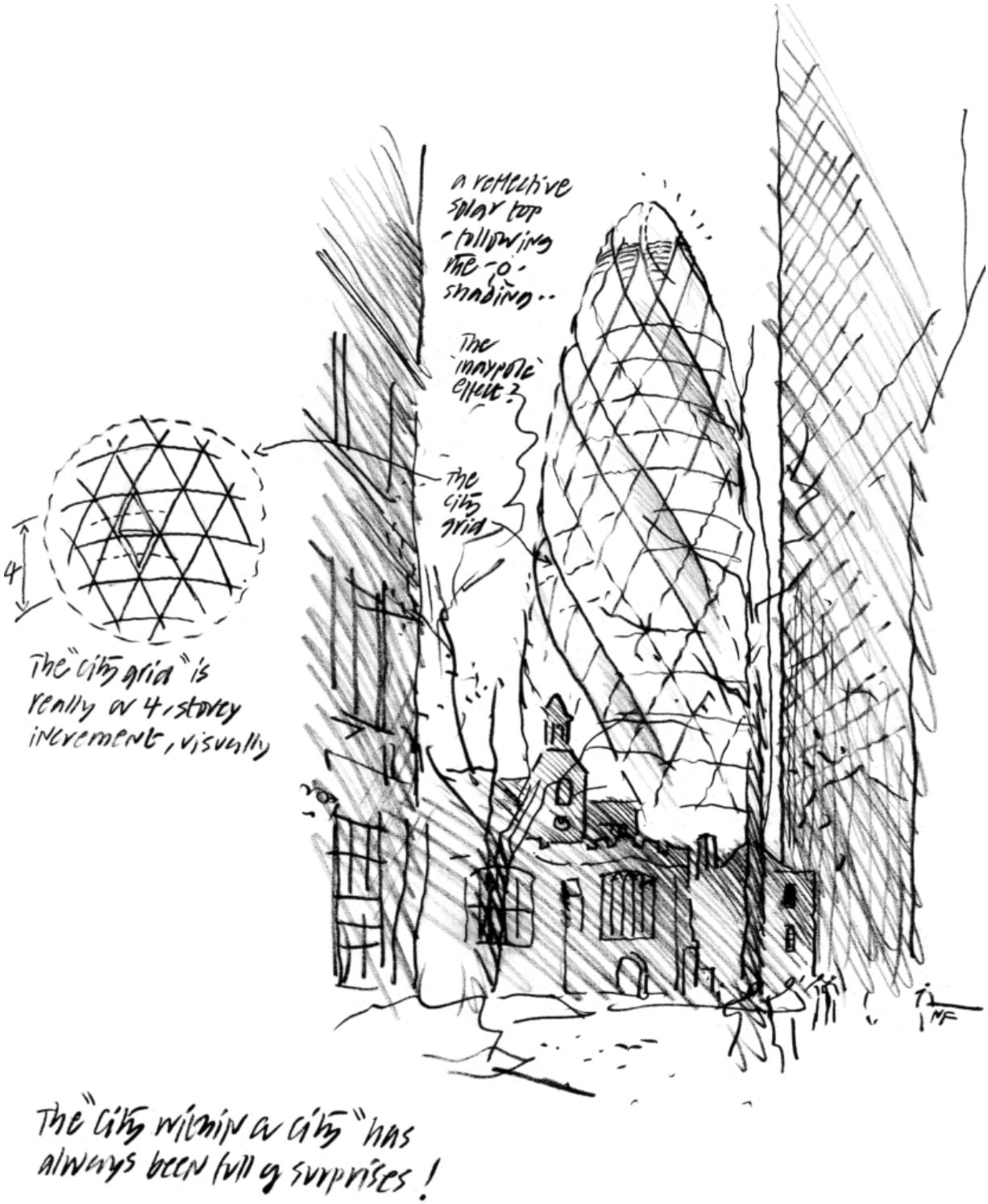

Fig. 1 Norman Foster's sketch for the headquarters of the Swiss Reinsurance Company, 30 St Mary Axe, in the historic core and the financial district of the City of London. Foster + Partners designed a fifty-storey tower 590ft (180 m) with a magnificent organic form that adds a distinctive identity to the skyline of the city.

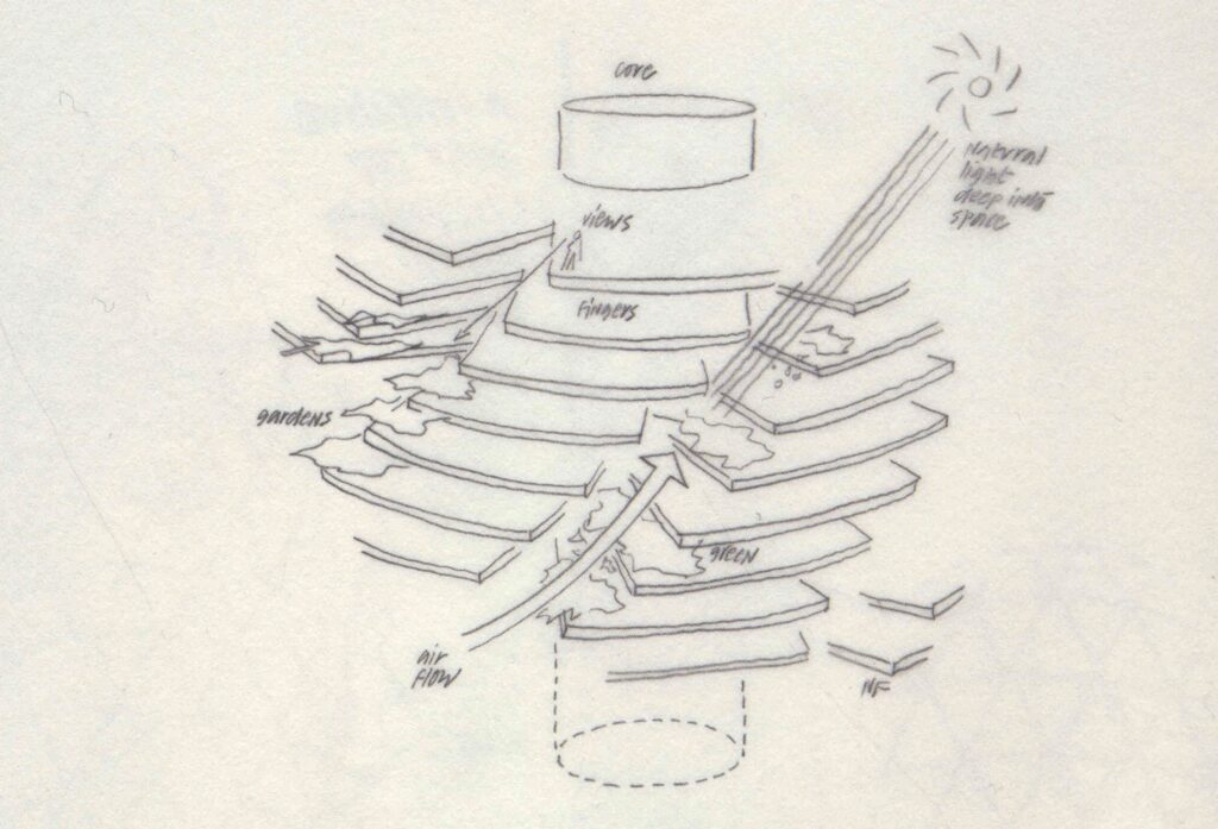

Fig. 2 Norman Foster's sketch illustrates the generative process: each floor is rotated by 5° relative to the one below around the central core with the pillars, bearing the vertical loads, the services, the stairs, and the lifts. From the core, six 'spokes' host the floorspace at each level. Each floorspace is detached from the next by a void triangular area about 20° wide. The vertically open areas create light wells for the height of the tower, up to the thirty-second floor. These open areas wound in coils to flow ventilation and natural lighting inside the building.

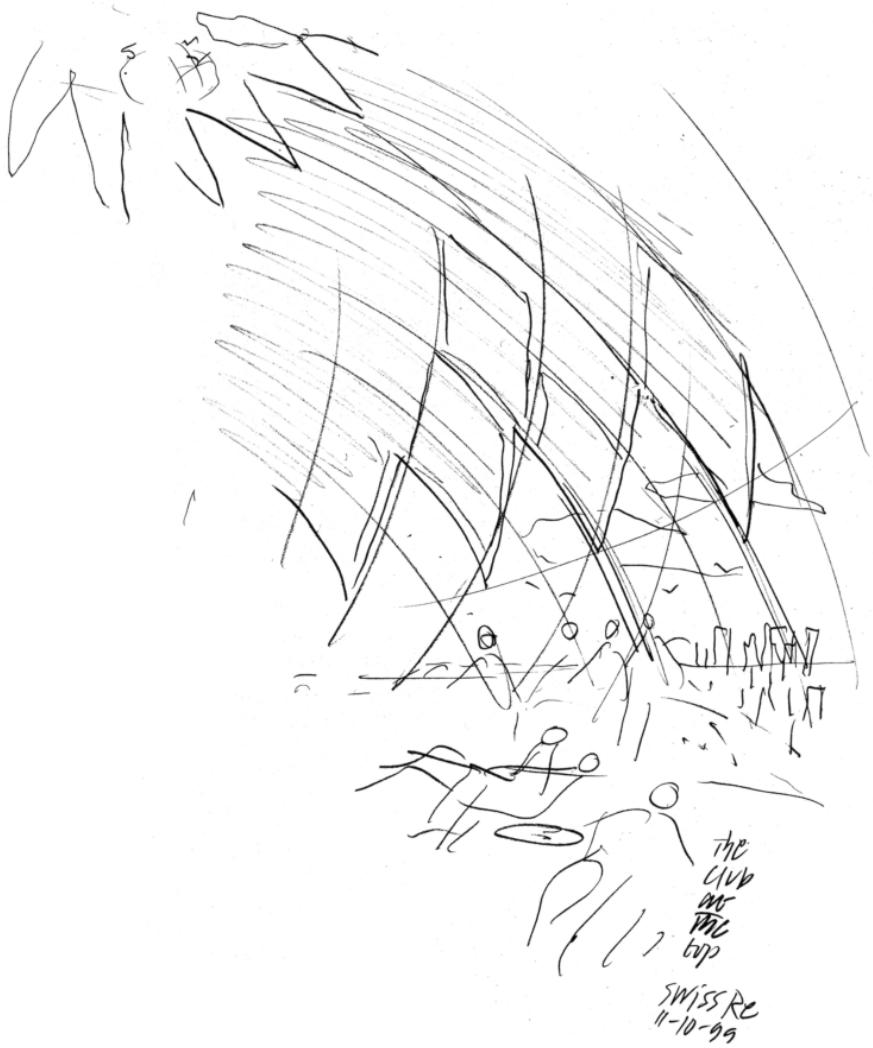

Fig. 3 The sketch of Norman Foster for the fully-glazed domed restaurant atop of the tower.

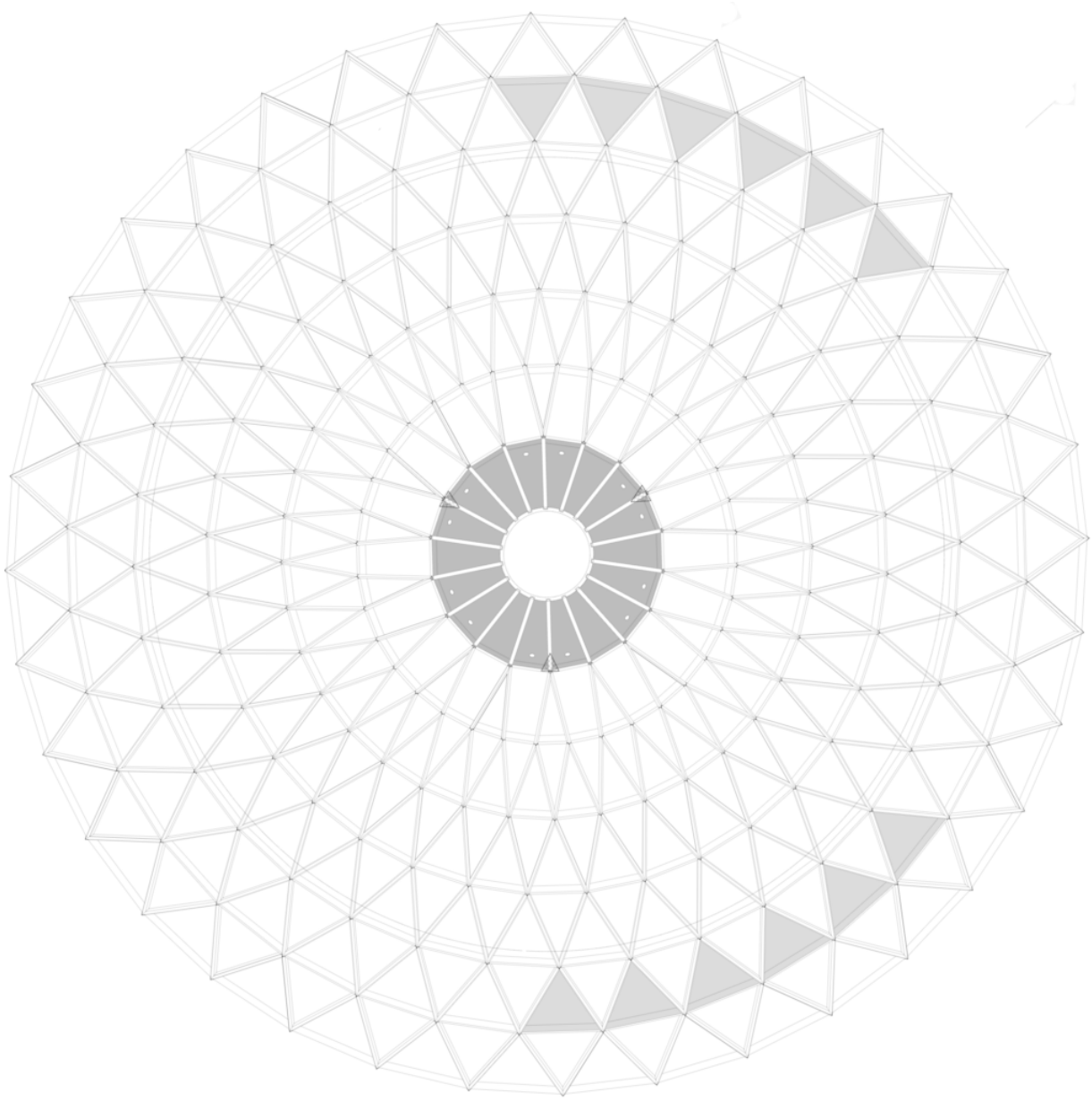

Fig. 4 The tapering profile of the tower allows reduced area at street level 160 ft (49 m), and reaches the largest diameter of 184 ft (56 m) at the 21st level, with the spatial climax at the glazed domed roof. The diagrid structure parametrises the A-shaped frames, and relieves the lateral loading from the central core. The A-shaped frames develop over two floors, and decrease the proportions from the 21st level respectively towards the pitched dome and the lobby level.

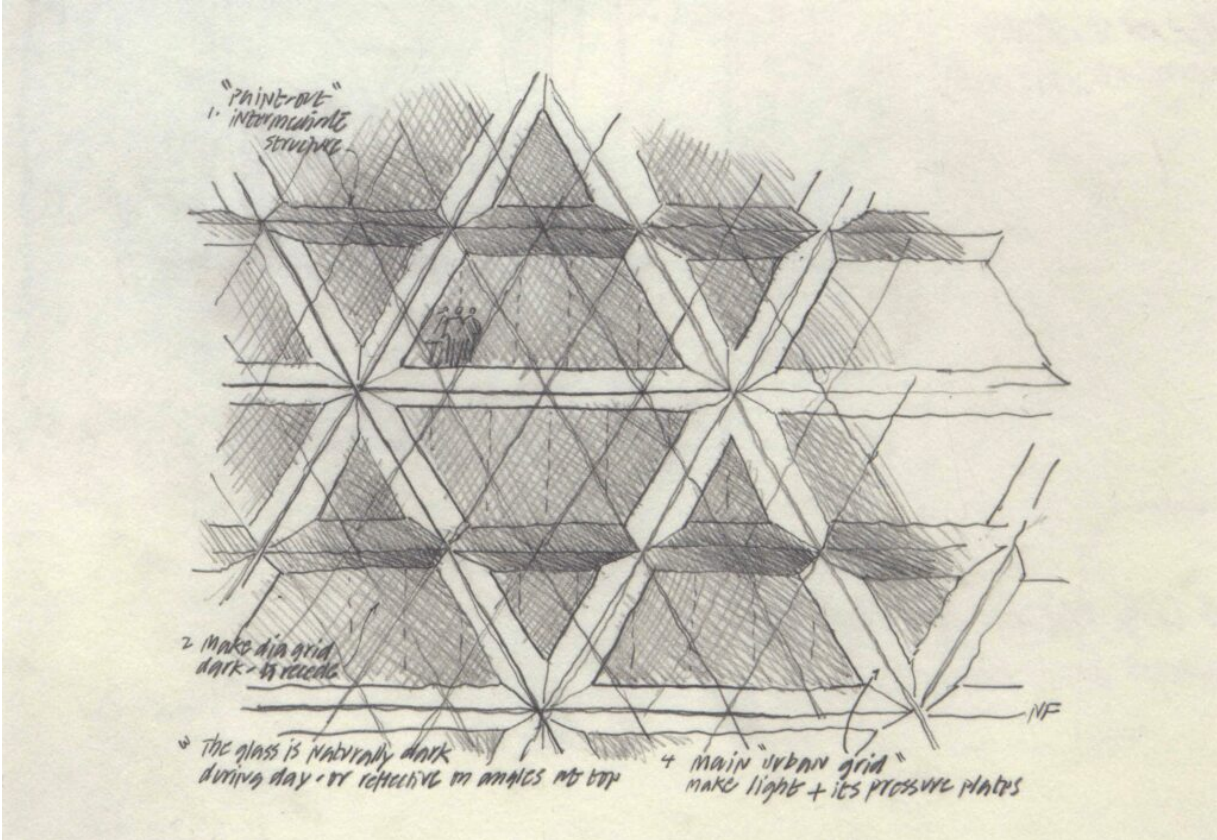

Fig. 5 Norman Foster's sketch makes clear how the A-shaped frames take on the diagrid geometry with two diagonal columns of tubular steel 20 in (508 mm) diameter, reflecting in the diamond-shaped backgrounds of the window panes.

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[2] E. T. Miret, J. J. Polivka and M. Polivka, *Philosophy of Structures,* (Berkeley: University of California Press, 1958), 331.

[3] P. L. Nervi, *Aesthetics and Technology in Building* (Cambridge, Mass.; London; Harvard University Press: Oxford University Press, 1966), 199.

[4] T. Oden, K.-J. Bathe, "A commentary on Computational Mechanics", *Applied Mechanics Reviews*, 31, 8 (1978), 1055-1056.

[5] "We can now wonder whether any type of imaginary surface, is constructible. The answer is in the negative. So: how to choose and how to judge an imagined form?" E. T. Miret, J. J. Polivka and M. Polivka, *Philosophy of Structures,* (Berkeley: University of California Press, 1958) 78.

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[7] A. Menges, "Instrumental geometry", *Architectural Design*, 76, 2 (2006), 46.

[8] Foster and Partners, “Modeling the Swiss Re Tower”, *ArchitectureWeek*, 238 (2005), http://www.architectureweek.com/2005/0504/tools_1-1.html (accessed 10 April 2022)

[9] “[Marjan] Colletti aptly quotes Deleuze stating: ‘The machine is always social before it is technical.’ The direct interaction between the designer and the equipment provides a feedback system of communication. He argues that the computer should ‘be regarded neither as abstract nor as machine’, but rather as an intraface.” C. Ahrens, “Digital Poetics, An Open Theory of Design-Research in Architecture”, *The Journal of Architecture*, 21, 2, (2016), 315; Deleuze’s passage is in G. Deleuze, C. Parnet, *Dialogues* (New York: Continuum International Publishing, 1987), 126-12; Colletti’s in M. Colletti, *Digital Poetics, An Open Theory of Design-Research in Architecture* (Farnham: Ashgate, 2013), 96.

[10] “We shall therefore first lay down, that the whole Art of Building consists in the Design, and in the Structure. The whole Force and Rule of the Design, consists in a right and exact adapting and joining together the Lines and Angles which compose and form the Face of the Building. It is the Property and Business of the Design to appoint to the Edifice and all its Parts their proper Places, determinate Number, just Proportion and beautiful Order; so that the whole Form of the Structure be proportionable. Nor has this Design any thing that makes it in its Nature inseparable from Matter; for we see that the same Design is in a Multitude of Buildings, which have all the same Form, and are exactly alike as to the Situation of their Parts and the Disposition of their Lines and Angles; and we can in our Thought and Imagination contrive perfect Forms of Buildings entirely separate from Matter, by settling and regulating in a certain Order, the Disposition and Conjunction of the Lines and Angles.” L. B. Alberti, *The Ten Books of Architecture* (London: Edward Owen, 1755 [1450]), 25.

[11] A. Zaera-Polo, “30 St. Mary Axe: Form Isn’t Facile”, *Log*, 4 (2005).

[12] See – along with Oden, Bathe, and Majowiecki – Paul Humphreys, “Computational Empiricism”, *Topics in the Foundation of Statistics*, ed. by B. C. van Fraassen (Dordrecht: Springer, 1997) and P. Humphreys, *Extending Ourselves: Computational Science, Empiricism, and Scientific Method*. (New York: Oxford University Press, 2004).

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[17] T. Oden, K.-J. Bathe, “A commentary on Computational Mechanics”, *Applied Mechanics Reviews*, 31, 8 (1978), 1056.

[18] “There are essentially two ways in which such education can operate, and they may be distinguished without difficulty. At one extreme we have a kind of teaching that relies on the novice’s very gradual exposure to the craft in question, on his ability to imitate by practice, on his response to sanctions, penalties, and reinforcing smiles and frowns. … The second kind of teaching tries, in some degree, to make the rules explicit. Here the novice learns much more rapidly, on the basis of general ‘principles’.

The education becomes a formal one; it relies on instruction and on teachers who train their pupils, not just by pointing out mistakes, but by inculcating positive explicit rules." C. Alexander, Notes on the Synthesis of Form (Cambridge, Mass.; London: Harvard University Press, 1964), 35.

[19] T. C. Bannister, "The Research Heritage of the Architectural Profession", *Journal of Architectural Education*, 1, 10 (1947).

[20] C. P. Snow, *The Two Cultures and the Scientific Revolution* (Cambridge University Press, 1962).

[21] A. Pérez-Gómez, *Architecture and the Crisis of Modern Science* (Cambridge, Mass.: The MIT Press, 1983).

[22] "Artists after the Internet take on a role more closely aligned to that of the interpreter, transcriber, narrator, curator, architect." A. Vierkant, *The Image Object Post-Internet*, http://jstchillin.org/artie/vierkant.html (accessed 21 September 2015). The artist Olafur Eliasson, for instance, started up his own architectural office (https://studiootherspaces.net/, accessed 30 March 2021), and the film director Wes Anderson authored the interior design of the Bar Luce, inside the Fondazione Prada in Milan.

[23] "Fuller … noted that species become extinct through overspecialization and that architects constitute the 'last species of comprehensivists.' The multidimensional synthesis at the heart of the field is the most invaluable asset, not just for thinking about the future of buildings but for thinking about the universe. Paradoxically, it is precisely when going beyond buildings that the figure of the architect becomes essential." Mark Wigley, *Buckminster Fuller Inc.: Architecture in the Age of Radio* (Zürich: Lars Müller, 2015), 71.

[24] J. Maeda, *How to Speak Machine: Laws of Design for a Digital Age* (London: Penguin Business, 2019).

[25] Le Corbusier, *The City of Tomorrow and its Planning* (London: John Rocker, 1929 [1925]), 1.

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