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Essay

Research in architecture and urban studies at Cambridge in the 1960s and 1970s: what really happened

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There has been much recent historical interest in the research that went on in Cambridge (England) from the mid-1960s at the centre for Land Use and Built Form Studies (LUBFS), with articles published by the historians Mary Louise Lobsinger and Sean Keller.[1] Leslie Martin, former chief architect of the London County Council, became Head of the Cambridge Department of Architecture in 1956. He and Lionel March set up the centre for Land Use and Built Form Studies in 1967. There had been research in building science and architectural history going on at Cambridge before that, but the programme of LUBFS was of a different kind and on a different scale. The centre grew fast and by 1973 had some 18 researchers and an equal number of PhD students.

I studied architecture at Cambridge from 1960 to 1965 and went immediately into research, working under Martin on university planning. I joined LUBFS on its foundation. In 1974 LUBFS was absorbed, with some other activities, into the Martin Centre, of which I became assistant director. I also became a director of Applied Research of Cambridge (ARC), a commercial company spun off from LUBFS. It is, I suppose, one of the minor penalties of a long life: but I have been surprised to find myself becoming a part of history, and being approached for reminiscences by a series of oral historians (including Lobsinger). One compensatory benefit, however, is that it is still possible for me to write in response to these historical accounts as someone who actually participated in the events in question.

First, some background: the design teaching under Leslie Martin was an orthodox Modernism, mingled with some remnants of Beaux Arts methods. We painstakingly transcribed quotations from Le Corbusier ('The plan is the generator') in classical Trajan lettering. Colin St John (Sandy) Wilson, Colin Rowe and Peter Eisenman taught studios. In the wider university there was an intellectual ferment around mathematical modelling in the social sciences, with the appearance of fat books on *Models in Geography* and *Analytical Archaeology*.[2] People in linguistics and anthropology were excited about Continental structuralism.

The 1950s and early 1960s saw the very first computers in universities. I should explain, for younger readers, that during this period there was just *one* computer in the whole University of Cambridge: the experimental EDSAC, succeeded by the EDSAC2 in the late 1950s, and by the Titan in the mid-1960s. These machines occupied whole rooms and had the power of the pocket calculators of the 1970s. In 1963 Ivan Sutherland, who had just completed his PhD at The MIT, gave a talk in Cambridge (England) about his 'Sketchpad' system, the *fons et origo* of all later computer-aided design tools.[3] Those of us students who attended could see that there was something potentially important here for

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architecture. We tried unsuccessfully to learn Titan Autocode, a rebarbative machine language. But it was only in the late 1960s that the shape of real architectural applications began to become a little clearer. Lobsinger states that: 'Under Martin's direction computer-facilitated research supported by systematic methods was initiated prior to the 1967 foundation of LUBFS.'[4] But this is much too early. I doubt if Leslie Martin ever touched a computer himself.

Land Use and Built Form Studies (LUBFS)

Lobsinger says that the name of LUBFS implies the idea of 'planning as comprising social and building sciences' which is obliquely true, but fails to explain its specific meaning. In fact the name refers to a piece of research on density that grew out of Martin's design studies with March for the redevelopment of government offices in Whitehall, London.[5] That work contrasted three generic types of 'built form'—freestanding 'pavilions' or towers, elongated terraces or 'streets', and closed 'courts'—and showed how they make use of land in different ways (Fig. 1). Counter-intuitively, the towers do *not* in general yield the highest densities. The same floor area as can be provided in a tower on a given number of storeys can—all other things being equal—be achieved in a street form on fewer storeys, and in a court form on still fewer storeys. (Computers were not used for the calculations, by the way, which were all made by hand.) These findings are alluded to in the logo of LUBFS (Fig. 2), which contrasts the plan of a courtyard on a square site (left) with the plan of a square tower on the same site (right). The plan area of the court is equal to the plan area of the tower.

The work thus produced generalised knowledge about the comparative performance—strictly in terms of density, all other things being equal—of three formal options for development. These options cover, at a highly abstract and schematic level, the whole range of possibilities for urban morphology. One can characterise *any* actual development in terms of the extent of what might loosely be called its 'toweriness', 'streetiness' or 'courtiness'. There was no suggestion that any of the forms was 'better' than the others on different criteria or on broader measures of value. Since the results are geometrical they are true for all time.

This original work on density and built form set the tone and philosophy of what was to follow at LUBFS. As Martin said, this research was 'not an attempt to … outline desirable goals. The object indicated here is the more modest one of attempting to understand the relationships that exist in the physical structure of the city. Once this is done it may be possible to indicate a wider range of choice and a greater opportunity for a variety of patterns of living to develop.'[6] And again, in the context of mathematical models more generally: 'We become aware of another way of looking at a design problem through which we can consider more effectively and rigorously the *ranges of choice* that are open to us.'[7] [My emphasis] Here is the absolute core of what LUBFS was about, from the outset, and the crucial point that Lobsinger and Keller misunderstand.

Building science, architectural science, urban science

From the work on density, research at LUBFS spread out rapidly across a wide range of topics in building,

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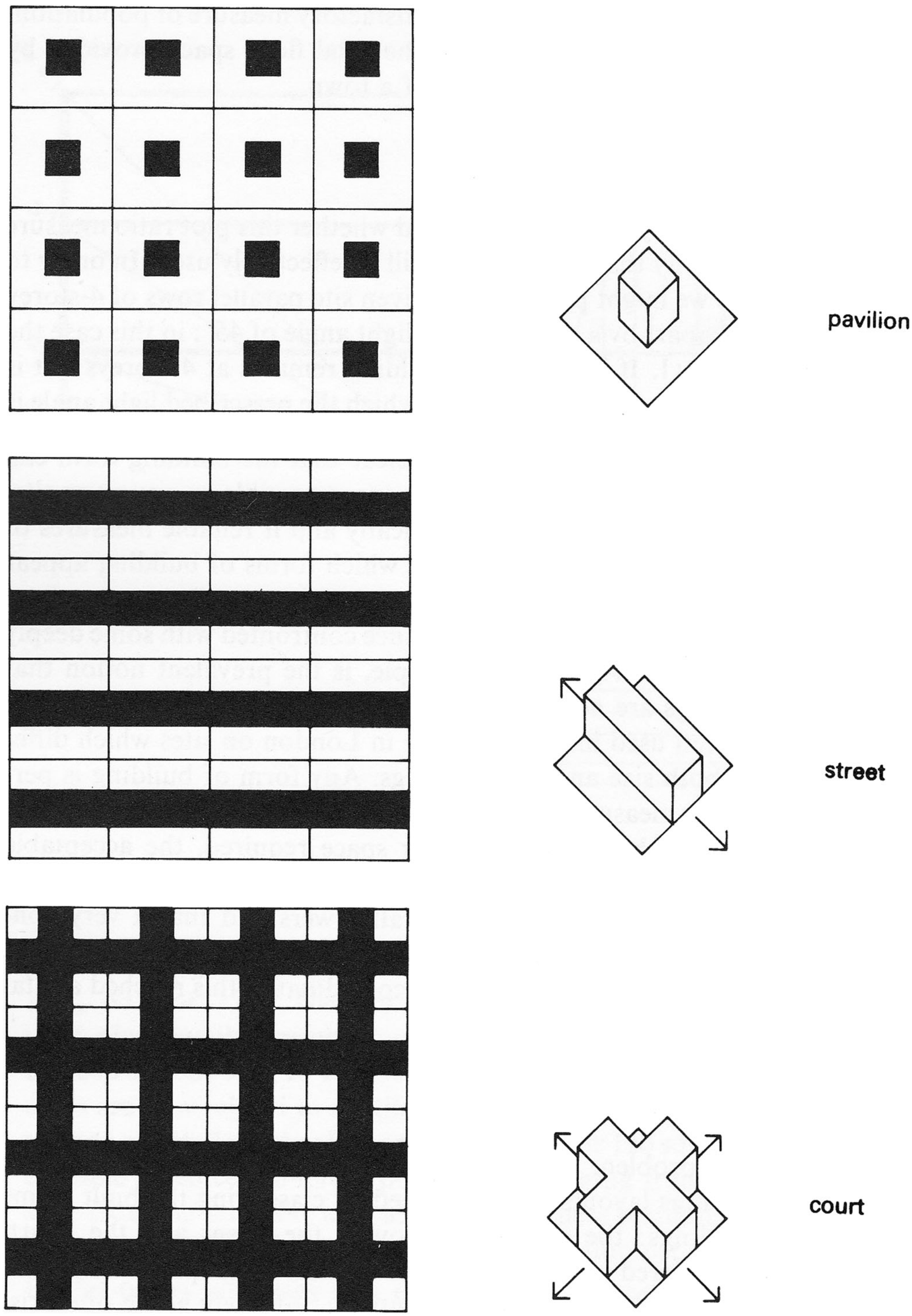

Figure 1. Three generic built forms—'pavilions', 'streets' and 'courts'—analysed by Leslie Martin and Lionel March in their work on densities, from *Urban Space and Structures* (1972).

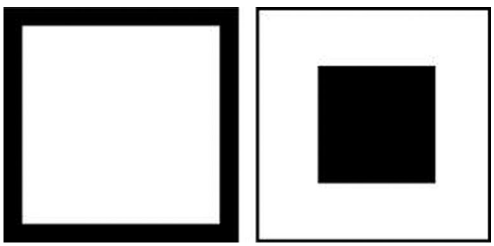

Figure 2. The logo of the Centre for Land Use and Built Form Studies, which contrasts the plan of a courtyard on a square site (left) with the plan of a square tower on the same site (right). The plan area of the court is equal to the plan area of the tower.

architecture and urban studies. Research in the applied physics of heat, light and sound in buildings, which had been going on at Cambridge well before LUBFS, continued under the leadership of Dean Hawkes. One major new initiative was the development of computer simulations of the internal environments of buildings, to replace or supplement earlier methods of hand calculation and the use of physical scale models.

There was other work in architecture. There was research, sponsored by government departments, on programming and briefing for different building types: housing, offices and universities. Historical studies were made of building bulk legislation, the acoustics of concert halls and British 'New Towns'. There was work on the geometry of built form and plan layout, to which I will return. One special focus was research in the mathematical and computer *representation* of designs, beyond the traditional architects' methods of hand drawing and physical modelling.

This was the subject of a book that Lionel March and I published in 1971, *The Geometry of Environment*.[8] The declared purpose was to introduce architects to some ideas in discrete mathematics, and to introduce mathematicians to some ideas in architectural geometry. The various chapters described ways of capturing, in formal mathematical terms, such properties as shape, symmetry, connectedness, contiguity and so on. Although there was little mention of computers, a second motive was to start to think about how architectural designs could be pictured and manipulated in two and three dimensions in the machine. The book was thus one contribution to a wider effort at that time to lay the mathematical foundations for computer-aided drafting and modelling.

At an intermediate scale between buildings and cities, there were attempts to simulate human behaviour using mathematical and computer modelling, as with, for example, models of the daily routines of university students, in which I was involved.[9]

At the urban scale, there was a major programme of research led by Marcial Echenique to develop integrated land use and transport models, building on a long tradition in urban and regional economics going back to the nineteenth century, and on the experience of urban simulation models built earlier in the 1960s in the USA, in particular Lowry's *A Model of Metropolis* of 1964.[10] Both university and urban models sought to *simulate* behaviour: they tried to recreate present patterns of activity in the context of complex spatial environments. In the urban case this meant simulating the decisions of households and firms in choosing locations and buying property, and estimating the resulting flows of traffic, dependent on the configuration of the transport network, on people having access or not to cars and the availability of public transport services. The models were calibrated (adjusted systematically) to fit the actual patterns of land use and transport in a city at the present and in the recent past. They were then used to explore future scenarios for incremental development: for example, the impacts on the whole urban system of new groups of buildings or land uses, of new roads, bridges or public transport services.

Thus the purpose was *not* to create large-scale urban master plans. It was to try to represent in formal and computational terms the *existing* patterns of land use and movement in cities; and from there to predict the effects of changes in the near future. In the words of Martin and March, describing the work: 'We are brought back to the question of what it is in the urban structure that we can study effectively; and that surely must be the reality of the present situation and the alternative strategies and options that are available to meet its need for growth and change. For the rest, we need not hope that we can enforce an environment by planning. It has to be built. We cannot assume that it will be built with any common unity of ideas. It is more likely to result from different interests and choices. It will not all be beautiful, but people will have been free to shape it, to make their own decisions and to learn from their actions.'[11]

One should see all this simulation work in the intellectual context of the times. Other disciplines such as geography were already working on the mathematical modelling of cities: not in order to design them, but to understand them. Modelling by computer offered the prospect of representing and studying complex systems, with all their many interacting factors, of the kinds that are found everywhere in the built environment and the behaviour of its occupants. In this wider sense many academic subjects became 'system-theoretical' from the 1970s. We were all systems theorists then.

All this research was reported in 77 Working Papers, in the two centres' *Annual Reports* and in the *Transactions of the Martin Centre*. (It should be appreciated that there were few academic journals that would publish this kind of material at that time.) These papers are admittedly not easy reading. Even so, it is perhaps significant that Lobsinger does not cite a single paper, and Keller cites just one.[12]

A key misconception is the broad idea that research in architecture involving mathematics and the use of computers must necessarily signal an attitude to architectural *design* that is technocratic, Taylorist, 'scientistic', that the design process can be made 'scientific' in some sense (an incoherent notion), and rejects any roles for poetry, aesthetics or the knowledge of history. Thus Lobsinger writes of 'positivistic processes for knowledge production' and a 'narrative of scientism'.[13] Keller talks of attempts by LUBFS 'to establish architecture as a science—as a field that would finally reject its artistic pretensions and produce a body of quantifiable results through research'.[14] Lionel March, Keller states, hoped that architecture could be made 'more rational and less intuitive, more scientific and less artistic'.[15] (Despite the very wide range of research at LUBFS, Lobsinger's and Keller's critiques are directed centrally at the architectural work.)

What this does is to elide *architectural science* with *architectural design*. Nobody I think gets worried about the relationship of traditional building science to the architectural design process. The science produces *knowledge* that architects can deploy when designing. The knowledge can also be used to make *predictions* about, and *evaluations* of the future physical performance of unbuilt designs: what the lighting levels will be, how much energy will be used, what the reverberation times of halls will be. The knowledge can be embodied in *tools* for designers: rules of thumb, guidelines, calculation procedures or computer software.

Supporting design with an architectural science, not making the design process 'scientific'

The accounts of Keller and Lobsinger become confused, however, when the scope of traditional building science is extended to other aspects of buildings such as their geometrical forms or the behaviour of their occupants. This seems to be treading on designers' toes. But the philosophy of the 'architectural science' at LUBFS envisaged precisely the same relationship to designing, as the relationship of building science to designing outlined above. This is very clear in Leslie Martin's statements about 'understanding relationships' and setting out 'ranges of choice' quoted earlier. The purpose was to *support* design with scientific understanding and tools, not to mechanise the design process or to make it 'scientific', whatever that might mean.

Keller and Lobsinger, however, misunderstand this. According to Keller, March proposed that an architectural science would 'enable design problems to be solved by mathematical methods'.[16] Lobsinger states that, at LUBFS, ' … mathematical means for theorizing principles were considered untainted by formal or intuitive prejudices about building form, programmatic function, or theoretical predisposition'.[17] This implies that the mathematical procedures somehow generated the forms themselves *de novo*. The truth is, however, that the tools developed at LUBFS were concerned with the representation and evaluation of forms produced (in whatever way, perhaps by intuition) *by designers*; or else with showing designers how the ranges of possible options available to them are limited by the laws of geometry and topology.

One reason I believe this confusion arises is that in order to produce repeatable and applicable results in this architectural science, it was necessary to simplify and devise abstractions of the forms of buildings. March introduced the term 'built forms' to mean ' … mathematical or quasi-mathematical models … which are used to represent buildings to any required degree of complexity in theoretical studies'.[18] All sciences are intrinsically reductive, of course. That is their point. The built forms of the original Land Use and Built Form Studies were featureless parallelepipeds with storey levels and flat roofs but little else by way of architectural detail—but that was sufficient (and necessary) for comparing just densities.

Keller mocks March who, he states 'almost completely neglected the expressive aspect of architectural form' and 'never discussed what a building would look like'.[19] This characterisation is completely absurd in itself. March is an historical scholar who has studied and written about Frank Lloyd Wright, published a book on Rudolph Schindler, and made deep analyses of Renaissance proportional theory. But more important, it misses the crucial point that an architectural historian might be interested in appearances, whilst an architectural scientist would be interested in 'naked' built form with all articulation, openings and decoration ignored. (And in the case of March these two could be one and the same person.)

The Fallacy of Imputed Philistinism

There should be a name for this: perhaps the 'Fallacy of Imputed Philistinism'. It is worth pointing out as an aside that, when the findings on density were applied in design, this was in Martin's own practice, whose style could hardly be characterised as technocratic or machine-aesthetic, but was in an Aalto-esque tradition, mostly in brick; and also in Richard MacCormac's practice, one of whose main points of reference was Wright.[20]

The founders of LUBFS were hardly philistine technocrats in other respects. Martin was one of the group of Modernist artists and critics who came together to produce the famous *Circle* anthology of 1937.[21] March was (and remains) a visual artist, and designed sets for opera. He became the Rector of the Royal College of Art. Lobsinger mentions that March had a Harkness Fellowship in the 1960s to study in the USA, and that while there he visited various advanced research centres that were the inspiration for LUBFS. But she fails to mention that he had the grant to study the buildings and writings of Wright. I edited and published *Form*, a quarterly journal of the arts. *The Geometry of Environment* used examples from the work of Palladio, Soane, Ledoux, Le Corbusier and, of course, Frank Lloyd Wright—including analyses of the 'textile block' decoration of Wright's La Miniatura and its symmetries.

Oddly, Keller and Lobsinger mention many of these activities in passing; but they still feel able to paint architectural researchers in Cambridge as insensitive to aesthetic concerns. They cannot see that these artistic interests were perfectly compatible with the research, which was concerned not with aesthetics but with measurable aspects of building form and performance. They cannot see that someone could be an architectural scientist on a Monday and a painter on a Tuesday.

Design methodology: not much at Cambridge

Because Keller and Lobsinger believe that the goal of architectural research at Cambridge was to make the process of designing 'scientific' and automatic, they conflate the work at LUBFS with that of the contemporary 'design methods movement'.[22] That movement had its origins in product design and engineering design. The chief British protagonists were Bruce Archer and J Christopher Jones, neither of them at Cambridge. The link to architecture and (tenuously) to Cambridge was made by Christopher Alexander, who was an undergraduate in the Cambridge School under Martin in the 1950s, and then went to Harvard to work on a PhD. Alexander turned this dissertation into a book, *Notes on the Synthesis of Form*, published in 1964.[23] The book argued for a systematic design method for generating architectural and urban designs on the basis of a mathematical analysis of functional requirements, using set theory and graph theory. (George Stiny has aptly commented that it should more properly have been called *Notes on the Analysis of Function*.)

The fascinating but logically flawed argument of the book (later renounced by Alexander himself) was certainly of great interest to some researchers at LUBFS, including myself. Lobsinger says rightly that Alexander was quoted in the introduction to a report on university planning produced in 1968, but goes on to say that the authors ' … mention their debt in departing from his work'.[24] What is more, Lobsinger will know from reading further, that that report did not offer any automatic or systematic design methods for university buildings, but was instead devoted to practical issues of programming (in the architectural sense) and university administration, as well as the beginnings of an approach to simulating student activity patterns.

Rather quickly those of us who had been initially intrigued by Alexander's proposed method came to see the fallacious nature of its underlying argument. I studied *Notes on the Synthesis of Form* intently for my PhD dissertation on biological analogy in architecture, published as *The Evolution of Designs* in 1979.[25] I devoted two chapters to showing how Alexander had slipped into a kind of functional determinism, like that of some of the most extreme functionalists of pre-War Modernism such as Hannes Meyer. This in turn arose out of a false equation, in effect, of cultural evolution with natural evolution.

March too was critical of Alexander in a paper on 'The Logic of Design and the Question of Value' of 1976. This was the preface to a book of collected papers, *The Architecture of Form*.[26] As Keller notes: 'Reacting to Alexander's mistakes, March introduces his own theory of architectural methodology [in fact a theory of the *logic* of the design process].'[27] In March's words: 'Any scientific approach to design must confront the issues raised by the pluralism of individual values and the autonomy of social choice; and must accept the conditionality of degrees of conviction about truth, rightness and goodness.'[28] 'Logic has interests in abstract forms. Science investigates extant forms. Design initiates novel forms. A scientific hypothesis is not the same thing as a design hypothesis. A logical proposal is not to be mistaken for a design proposal.'[29]

Keller tries to present this as a rowing back, a withdrawal by March from an earlier belief that designing could be automated: 'By the mid-1970s even those most committed to "architectural science" clearly saw that a mathematical approach was not going to lead directly to architectural results [ie, produce designs automatically]. Even with the new analytical power of computers, no direct path led from functions to forms.'[30] But this was *never* the aim of LUBFS architectural scientists (with one exception), even in the early days. 'The Logic of Design' was a reiteration, amplification and clarification of a philosophy that was present right from the start, as I have shown with Martin's comments on the studies of density and built form.

Optimisation

If one believes mistakenly, as Lobsinger and Keller do, that the ambition of much of the LUBFS work, at least in the 1960s, was to get computers to design buildings, then it would follow that this process would seek to *optimise* designs in some automated way. Lobsinger uses the word 'optimal' repeatedly in her critique: 'The goal was to provide optimal solutions rather than definitive end forms for a particular problem.'[31] Such 'optimal' forms would by definition be unique, and would be (supposedly) better than all others on some measurable criterion. There were in fact only two pieces of work that sought to optimise forms or designs in the whole varied output of LUBFS, and in one of these the word was used in a very different, specialised sense.

This was in a series of studies by March of 'Elementary models of built forms'.[32] These were geometrical exercises involving simple cuboids (the built forms) to explore basic questions such as: 'What shape should a building be to reduce heat losses?' or 'What shape should a building be to reduce its costs?' As March indicates, these are issues about which practitioners have vague intuitions or rules of thumb. March varies the relevant parameters—height, width and depth of the forms, and so on—and uses algebraic analysis to derive specific dimensions for which the stated goal—cost, heat loss—is minimised. This is indeed a process of optimisation, using the term in its technical mathematical meaning. (Again, all the calculations were done by hand.)

But there is clearly no claim that the forms are 'optimal' in any wider sense, or any suggestion that architects should go away and build real buildings with these forms. Indeed the (mathematically) optimal form on one criterion might be different from the optimal form on some other criterion. March shows how different initial assumptions in the *same* exercise can lead to *different* 'optimal' outcomes. The purpose was, of course, didactic: to explore the generic relationships of form to performance, as with Martin's 'ranges of choice'. It was to show that some popular design lore needed to be questioned and explored; as for example the idea that 'High tower blocks make good use of land'—a false belief that persists among architects today.

Optimisation of plan layout

There *was* one piece of research, by Tom Willoughby, a research student at LUBFS, to which the historians' strictures about optimisation *do* apply. Willoughby made further developments to computer methods, pioneered elsewhere, for producing plan layouts automatically, in which the goal was to minimise the total amount of pedestrian travel by the occupants.[33] The methods thus did indeed produce single supposedly 'optimal' designs. Two distinct approaches were taken: to permute all activities between all rooms in a fixed, predetermined plan arrangement, or to add rooms and activities in sequence to a growing plan, starting with the room/activity that was most highly connected (in terms of frequency of journeys) to all others, then the next most highly connected, and so on. Much of this work, outside Cambridge, went under the banner of the design methods movement.

The work by Willoughby was, however, unusual for LUBFS, and quite peripheral. Others recognised directly that there were serious logical problems involved, even on the techniques' own terms. The methods made use of survey data on people's movements in existing buildings of similar type, in order to make predictions of the numbers of journeys in the new building. But this ignored the strong possibility that, in a new building, the pattern and frequencies of journeys would change: that layout and behaviour interact. Again the methods ignored all other quantifiable aspects of performance such as lighting, ventilation and views. The 'additive' methods created very deep concentric plans with ragged boundaries, impossible to light naturally at the centre, and with no clear structure to their circulation systems. These criticisms were made in a series of LUBFS Working Papers produced in 1969/70 by Philip Tabor, who also worked on circulation and plan layout, as well as in *The Geometry of Environment* in 1971.[34] Because of their failings, the methods have never been applied in architectural practice, even though academic research on them continues to this day.[35]

Tabor took a contrasting approach. He devised a series of simple plans of a variety of generic shapes—linear, cruciform, court-shaped—and measured the distances between all pairs of rooms. The purpose was to compare these plans in terms of their suitability for *generic* patterns of movement: that is to say, how overall geometry is related to the resulting pattern of distances between rooms within schematic plans. There was no attempt to predict people's actual movements in specific plans. These were measurements made on built forms. Here is yet another exploration of Martin's 'ranges of choice' and their comparative performance.

Keller himself reports this debate reasonably reliably, and quotes Tabor's explicit rejection of 'that most extravagant of fancies, completely automatic design'. In Keller's words, Tabor concluded 'that quantifiably optimized architectural solutions were largely impossible'.[36] But where Keller is incorrect is in presenting this as a dawning realisation among members of LUBFS generally, and March in particular, of the fallaciousness of a supposed previous belief in the automation of design. Notice that Tabor was writing in 1969 and 1970 at the conclusion of a PhD that he began when LUBFS was founded in 1967.

Of course it was the hope that all the work at Cambridge might help practitioners themselves to produce designs that were *better* in one way or another. But that is a very different matter from optimisation.

Exhaustive enumeration of plan layout

I also pursued the question of plan layout, but took a diametrically different path. I came to realise that, if attention was confined to plans consisting of rectangular rooms within an overall rectangular boundary, it was feasible to enumerate *all* possibilities for plans exhaustively, and set them out in a catalogue.[37] My initial work was done by hand. Keller reproduces this manual enumeration, and is scornful that 'Exhaustive results could be given for only five rooms or fewer—an architecturally trivial number.'[38] But he cannot have followed up later publications with Bill Mitchell and Robin Liggett, where we reported results for computer enumerations of up to 10 rooms.[39] Later still, Ulrich Flemming developed the DIS ['dissection'] software with which, if the search was limited by some set of specified constraints, then all allowable possibilities with up to 20 rooms could be enumerated.[40] (These limits are imposed by the fact that the numbers of possible plans for successive numbers of rooms grow rapidly, to the point where not even computers can count them.)

Readers will appreciate, I hope, that this is utterly different from the production of single 'optimal' designs. It can in principle let architects see the complete 'ranges of choice' allowed by the laws of geometry and topology, for small rectangular plans within the limits on size. The catalogues can be sieved to produce all plans meeting some specified set of criteria: limits on the sizes and shapes of rooms, desired relationships of adjacency of rooms, specified orientations and so on. A very tight set of specifications of this kind might produce no plans at all, showing that the combined requirements set an impossible task and can never be satisfied. A looser set of requirements might produce a variety of possible plans, from which designers might make further selections.

This work also never found applications in practice. But this was for a very different reason, at least when we first published: because we were not believed. Mitchell told an architect colleague in Los Angeles what we had done, and he said flatly 'That's impossible'. Mitchell and I submitted an article describing the work to the British *Architects' Journal*. The piece was refused by the Editor in a letter of scarcely concealed hysteria. 'This work is strictly non-architectural … It has nothing to do with architecture.'

Undeterred, Frank Brown and I used the DIS system in the 1980s to study some historical episodes in the design of small twentieth-century house types.[41] And over the last decade I have been developing a new approach to the exhaustive enumeration of plan layouts, which by dealing with *zones* rather than individual rooms, lifts the representation to a higher level, and breaks the combinatorial limits on the previous room-level work.[42] It is perhaps needless to repeat that my purpose is didactic and explanatory, not to offer a design method. Maybe this time people will believe that such a thing can be done.

'Somewhere in the Cambridge fens architectural science committed computer-aided suicide'

On the basis of these misconceptions, Keller confects a narrative arc in which in 1967, members of LUBFS set out to automate designing and make architectural design scientific. However, they realised by the mid-1970s that this was a delusion, an impossible dream. March's vision was in ruins: 'Somewhere in the Cambridge fens architectural science committed computer-aided suicide.'[43] Lionel March can speak for himself. But if this is a verdict on the whole of LUBFS and its lasting importance, it is a complete travesty.[44]

Keller even makes the outrageous proposition that the only effective legacy of LUBFS is the curvilinear 'parametric' form making of the late 1990s, in the work of Gehry, Hadid and followers.[45] This notion seems to be based on the tenuous link suggested by the use of the word 'parametric' in both cases. But the (rectangular) built forms of LUBFS are parameterised—the underlying forms are kept the same while their dimensions are varied—in order to study the relation of form to performance. And in the work on exhaustive enumeration of forms and plans, these are again parameterised to remove dimensions, since it is the basic 'dimensionless' configurations that can be counted. What is more, the software that allowed the creation of the doubly curved surfaces of 1990s 'parametricism' came not from architecture but from the aerospace and product design worlds.

So if this announcement of the death of LUBFS is distinctly premature, what was the continuing influence of the Centre? Work in building science and the simulation of environmental performance, especially energy use, continues in the Martin Centre to this day. Cambridge was not the only place in the world where software for simulating the physics of heat, light and air movement in buildings was pioneered in the 1960s and 1970s. But it was one of the first. This software is now in the computers of every environmental consultant in practice. It has become so universal as to be almost invisible. But it had its origins in university research.

The work on integrated land use and transport modelling found applications in cities around the world, at first through Applied Research of Cambridge, and then through Echenique's own international consulting company. There was a counter-reaction in the 1970s, focussed in a much-discussed paper by Douglass Lee called 'Requiem for Large Scale Models'.[46] Lee criticised the models for being cumbersome to use, for simplifying the spatial representation of cities into small numbers of zones and for encouraging excessive attention to the demands of car transport. This was a part of the general reaction against comprehensive planning of the period, and the move in academic departments of planning away from a direct interest in the spatial and geometrical properties of the physical environment, towards social and economic concerns. But despite Lee's obituary, the models continued in use and are widespread today. With increases in computing power and graphical interfaces they have become much more useable and responsive; and it has become possible to treat urban morphology at a more detailed level and to introduce many more measures of evaluation.

The work at LUBFS on mathematical tools for 2D and 3D representation of buildings provided part of the foundation, as mentioned, for computer-aided drafting and modelling systems. Development of this type of software was the main activity, alongside urban modelling, of Applied Research of Cambridge, the company set up by members of LUBFS in 1969. As with environmental software, ARC was not the only company in the field, but it was one of very few, and produced the forerunners of today's AutoCAD and Microstation (but running in the early years on mainframes and mini-computers). ARC started with one half-time employee and doubled in size every year. By the late 1970s it had a multi-million pound turnover, with wholly owned subsidiaries in North America and Australia, and a joint venture in Japan. The company was sold to a division of the McDonnell Douglas Corporation in 1984 for 12 million dollars. Computer-aided design tools in architecture are now routine and unremarkable. But in the 1970s they were new, and again came out of university research.

Keller has some knockabout fun with a couple of drawings by March and a colleague from the Cambridge Mathematical Laboratory, Robin Forrest, of Mies van der Rohe's Seagram Building (Fig. 3). Forrest's diagram shows the Seagram distorted by a 'shear' transformation.[47] Keller sees in this figure, 'slipping out of March's research, early signs of a new formal vocabulary of transformations, processes, and antimaterialism that would come to define the architectural avant-garde of the 1980s and that since has evolved into an entire mode of

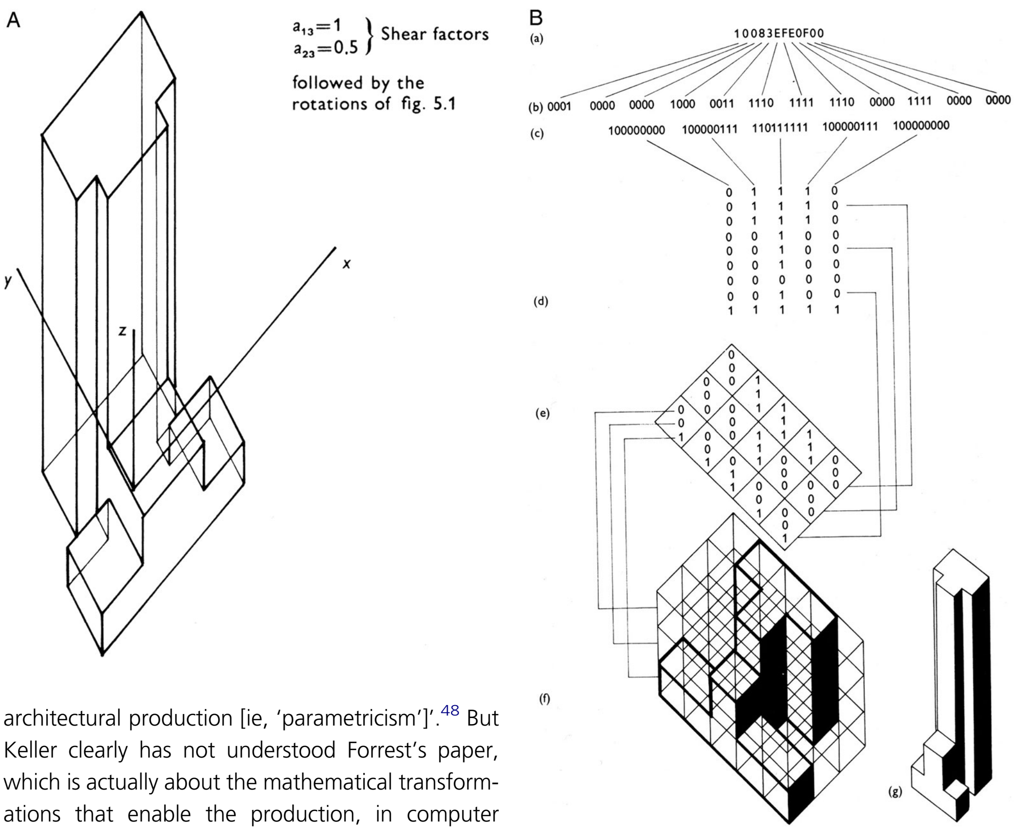

Figure 3A. The form of Mies van der Rohe's Seagram Building in New York, distorted by a shear transformation, from Robin Forrest, 'Transformations and matrices in modern descriptive geometry' (1976); 3B. The form of the Seagram encoded as a string of binary numbers, from Lionel March, 'A Boolean description of a class of built forms' (1976).

architectural production [ie, 'parametricism']'.[48] But Keller clearly has not understood Forrest's paper, which is actually about the mathematical transformations that enable the production, in computer graphics, of axonometrics, isometrics and perspectives. Meanwhile March's diagram shows a method of encoding the geometry of the Seagram with a long string of binary numbers (0s and 1s):[49] another symptom for Keller of this 'new formal vocabulary'. However, the purpose of encoding built forms in this way is so that all possibilities can be counted. The form of *every* building that is designed today with computer aids is represented in the machine at the lowest level in (extremely) long sequences of binary numbers.

And what, finally, of the original Land Use and Built Form Studies on density? That work was applied in the 1970s, as I mentioned earlier, in Leslie Martin's own practice and in some schemes by Richard MacCormac. It was then largely forgotten, to be revived again in 1999 by Richard Rogers and his Urban Task Force.[50] One of Martin's key papers has been republished.[51] Two researchers at the Technical University Delft, Meta Berghauser Pont and Per Haupt, have made measurements in the last decade for large numbers of Dutch housing schemes and shown how the theoretical findings of Martin and March are borne out in real practice.[52] The issue of built form and density is taking on a renewed urgency today with the appearance of large numbers of tall buildings, even in locations where low-rise forms can put the same floor area on the same sites. Lionel March tells me that there is a major but invisible monument to him and Leslie Martin in the centre of London: there are (still) no towers in Whitehall.

Notes and references

1. See Mary Louise Lobsinger, 'Two Cambridges: Models, Methods, Systems, and Expertise', in, Arindam Dutta, ed., *A Second Modernism: MIT, Architecture, and the 'Techno-Social' Moment* (Cambridge, Mass., The MIT Press, 2013), pp. 651–685 (the 'second Cambridge' here is, of course, Cambridge, Massachusetts); Sean Keller, 'Fenland Tech: Architectural Science in Postwar Cambridge', *Grey Room*, 23 (Spring, 2006), pp. 40–65. (The word 'Tech' here does *not* refer to information technology, but to a visitor's flippant suggestion in 1961 that the hallowed university, given its growing engineering and mathematical focus, should be reclassified as a technical college.) There is a third account of LUBFS: Altino Joao Magalhaes Rocha, *Architecture Theory 1960–1980: Emergence of a Computational Perspective* (PhD dissertation, The Massachusetts Institute of Technology, 2004). This paints a very interesting picture of the immediate post-War state of British architecture and building research, which created the context for the research at Cambridge. It also describes the influence on Leslie Martin of his friend the scientist J. D. Bernal. In general, the description of LUBFS and its philosophy is more reliable than those of Keller and Lobsinger, in part no doubt because Bill Mitchell, who was closely involved with the Cambridge work in the 1970s, was on Rocha's doctoral committee.
2. Peter Haggett, Richard Chorley, eds, *Models in Geography* (London, Methuen, 1967); David L Clarke, *Analytical Archaeology* (London, Methuen, 1968).
3. Ivan Sutherland, *Sketchpad: A Man-Machine Graphical Communication System* (PhD dissertation, The Massachusetts Institute of Technology, 1963; published: New York, Garland, 1980).
4. M. L. Lobsinger, 'Two Cambridges', 2013, *op. cit.*, p. 665.
5. Published in several places, of which the most accessible is Leslie Martin, Lionel March, eds, *Urban Space and Structures* (Cambridge, Cambridge University Press, 1972), chapters 1 and 2: in particular, 'Speculation 4', pp. 34–38. The original publication was 'Land Use and Built Forms', *Cambridge Research* (April, 1966).
6. L. Martin, L. March, eds, *Urban Space and Structures*, *op. cit.*, p. 2.
7. Lionel March, Philip Steadman, *The Geometry of Environment* (London, Royal Institute of British Architects, 1971): Foreword by Leslie Martin, p. 6.
8. *Ibid*. A paperback edition of *The Geometry of Environment* was published by The MIT Press in 1975. Despite this, neither Lobsinger nor Keller mentions the book, perhaps because it did not carry the LUBFS banner.
9. Again, the most accessible source is L. Martin, L. March, eds, *Urban Space and Structures*, *op. cit.*, chapters 5 and 6.
10. *Ibid*., chapters 7, 8 and 9; and see also, I S Lowry, *A Model of Metropolis* (Santa Monica, CA, Rand Corporation, 1964).

11. L. Martin, L. March, eds, *Urban Space and Structures*, *op. cit.*, p.163.
12. It is notable that Lobsinger and Keller also make only a few references to the books published by members of LUBFS over this period, with the one exception of *The Architecture of Form*. That is where the philosophy of the research was explained at length. Instead they rely on an edition of *Architectural Design* magazine (May, 1971), which provided more accessible summaries. The issue opened with a combative editorial by Lionel March with Peter Dickens and Marcial Echenique, which was perhaps deliberately intended to provoke practitioners (and historians?). The editorial nevertheless presents the same LUBFS philosophy as I have outlined here.
13. M. L. Lobsinger, 'Two Cambridges', 2013, *op. cit.*, p. 657.
14. S. Keller, 'Fenland Tech', *op. cit.*, p. 41.
15. *Ibid*., p. 42.
16. *Ibid*.
17. M. L. Lobsinger, 'Two Cambridges', 2013, *op. cit.*, p. 672.
18. L. Martin, L. March, eds, *Urban Space and Structures*, *op. cit.*, p. 56.
19. S. Keller, 'Fenland Tech', 2006, *op. cit.*, p. 48.
20. See I. Latham, ed., *Building Ideas—MJP Architects* (London, Right Angle Publishing, 2010).
21. Leslie Martin, Ben Nicholson, Naum Gabo, eds, *Circle: International Survey of Constructive Art* (London, Faber and Faber, 1937).
22. Lobsinger also discusses work in both Britain and the United States on the application of ideas from cybernetics to architectural design methods, including Gordon Pask's collaboration with the architect Cedric Price, and Nicholas Negroponte's Architecture Machine group at The MIT. But cybernetic thinking played no such role at LUBFS, despite the fact that Pask graduated from Cambridge, and the cybernetic theorist and architect John Frazer worked for a time at the Cambridge School of Architecture.
23. Christopher Alexander, *Notes on the Synthesis of Form* (Cambridge, Mass., Harvard University Press, 1964).
24. M. L. Lobsinger, 'Two Cambridges', 2013, *op. cit.*, p. 672.
25. Philip Steadman, *The Evolution of Designs: Biological Analogy in Architecture and the Applied Arts* (Cambridge, Cambridge University Press, 1979), chapters 12 and 13.
26. Lionel March, 'The Logic of Design and the Question of Value', in, L. March, ed., *The Architecture of Form* (Cambridge, Cambridge University Press, 1976), pp. 1–40.
27. S. Keller, 'Fenland Tech', 2006, *op. cit.*, p. 56.
28. L. March, 'The Logic of Design', *op. cit.*, p. 5.
29. *Ibid*., p. 15.
30. S. Keller, 'Fenland Tech', 2006, *op. cit.*, p. 56.
31. M. L. Lobsinger, 'Two Cambridges', 2013, *op. cit.*, p.673. (But what are 'definitive end forms'?)
32. In L. Martin, L. March, eds, *Urban Space and Structures*, *op. cit.*, Chapter 3, pp. 55–96.
33. See Tom Willoughby, 'Understanding building plans with computer aids', in, D. Hawkes, ed., *Models and Systems in Architecture and Building* (Lancaster, Construction Press, 1975), pp.146–53. Research in automated layout elsewhere than Cambridge had begun as early as 1949, with the work of Alphonse Chapanis, and continued through the 1950s.
34. Philip Tabor, 'Traffic in Buildings'. There were four LUBFS Working Papers under this rubric: numbers 17 to 20 inclusive (Cambridge, Land Use and Built Form Studies, 1969/70).
35. See Robin Liggett, 'Automated facilities layout: past, present and future', *Automation in Construction*, 9 (2000), pp. 197–215.
36. S. Keller, 'Fenland Tech', 2006, *op. cit.*, p. 55: quoting P. Tabor, 'Analysing Communication Patterns', in,

L. March, ed., *The Architecture of Form*, 1976, *op. cit.*, Chapter 9, p. 284.

37. Philip Steadman, 'Graph-theoretic representation of architectural arrangement', *Architectural Research and Teaching*, 2 (1973), pp.161–172.
38. This figure actually shows all possibilities with up to *six* rooms.
39. William J Mitchell, Philip Steadman, Robin S Liggett, 'Synthesis and optimisation of small rectangular plans', *Environment and Planning B*, 3 (1976), pp. 37–70. Note that 'optimisation' is used here in the technical mathematical sense explained in the text and refers to the production of plans in which total area was maximised or minimised. *All* dimensioned possibilities for each plan configuration would then lie between those extremes.
40. Ulrich Flemming, 'Wall representations of rectangular dissections and their use in automated space allocation', *Environment and Planning B*, 5 (1978), pp. 215–32.
41. Frank Brown, Philip Steadman, 'The analysis and interpretation of small house plans: some contemporary examples', *Environment and Planning B*, 14 (1987), pp. 407–438.
42. Philip Steadman, *Building Types and Built Forms* (Leicestershire, Troubador, 2014).
43. S. Keller, 'Fenland Tech', 2006, *op. cit.*, p. 62.
44. Keller attempts to link the supposed 'failure' of LUBFS to the near closure of the Cambridge School of Architecture in 2004 after the Government's Research Assessment Exercise (RAE) of 2001, despite the fact that the events in question were thirty years apart, and Martin and March were long gone. The causes of that crisis were complex, but they centred on the fact that studio teachers of architecture were publishing insufficient research to meet the requirements of the RAE, not on any failings of the still thriving Martin Centre.
45. S. Keller, 'Fenland Tech', 2006, *op. cit.*, pp.43, 62.
46. Douglass Lee, 'Requiem for large-scale models', *Journal of the American Institute of Planners*, 39 (1973), pp. 163–178.
47. Robin Forrest, 'Transformations and matrices in modern descriptive geometry', in, L. March, ed., *The Architecture of Form*, 1976, *op. cit.*, pp. 159–184.
48. S. Keller, 'Fenland Tech', 2006, *op. cit.*, p. 43.
49. Lionel March 'A Boolean description of a class of built forms', in, L. March, ed., *The Architecture of Form*, 1976, *op. cit.*, pp. 41–73.
50. Richard Rogers, *Towards an Urban Renaissance* (London, The Urban Task Force, 1999).
51. Leslie Martin, 'The grid as generator', *Architectural Research Quarterly*, 4 (2000), pp. 309–322.
52. Meta Berghauser Pont, Per Haupt, *Spacemate: The Spatial Logic of Urban Density* (Delft, Delft University Press, 2004).