4 Bewildered, the form-maker stands alone

Computer architecture and the quest for design rationality

Theodora Vardouli

In its winter 1964–1965 issue, the journal *Landscape* featured a two-and-a-half page review article titled "Notes on Computer Architecture." The reviewer was geographer Yi-Fu Tuan, at the time still a junior faculty member at the University of New Mexico. The reviewee was Christopher Alexander, a Cambridge University-trained architect and mathematician, who had just completed five years of doctoral work at Harvard and joined, as a faculty member, the Department of Architecture at the University of California, Berkeley. A play on *Notes on the Synthesis of Form*—the title of Alexander's dissertation-based book released by Harvard University Press in 1964, and the focus of Tuan's review —"Notes on Computer Architecture" was not about digital computers. Or rather, not directly so. Instead, it was about casting aspects of design in logical and mathematical terms: devising step-wise descriptions of design processes amenable to potentially automatable mathematical analysis.

Tuan tied the use of such logico-mathematical formalisms with metaphors of revealing, of making visible what was before hidden. The pivotal implication of using a "logical structure […] made up of mathematical entities" (1964: 12), Tuan remarked, was the possibility of conducting an "explicit mapping of the [design] problem's structure" (1964: 14). "Problem" here denoted the quantitative and qualitative requirements that physical things (spanning from kettles to urban dwellings) ought to satisfy in a particular situation. In *Notes*, Alexander presented a method for breaking down ("decomposing") these requirements into independent sub-groups by evaluating "conflicts" between them. This analytical method dictated the order ("program") by which a designer ought to respond to the different requirements, by making abstract sketches ("diagrams") that addressed the simpler sub-groups and then combining them in the order indicated by the "program." The visual summary of the method was a mathematical representation called a "tree." "Trees" were special cases of "graphs," mathematical entities that consisted of points representing abstract objects and lines representing their relationships. Alexander used "trees" to represent the hierarchical structure of the design "problem" and also the steps by which the designer was to tackle it.

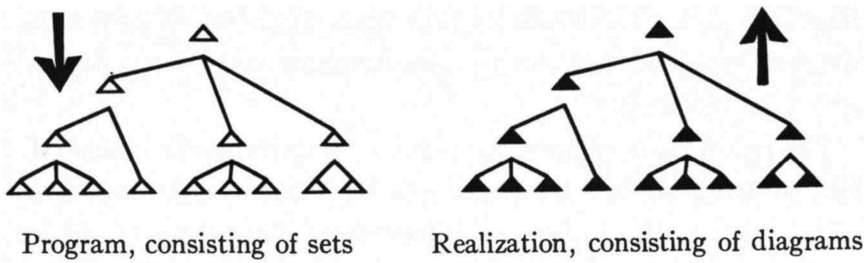

Figure 4.1 Image taken from the *Notes*, showing the "program" and the "realization" tree. The image opened Tuan's review. Source: *Notes on the Synthesis of Form* by Christopher Alexander, Cambridge, Mass.: Harvard University Press, Copyright © 1964 by the President and Fellows of Harvard College. Copyright © renewed 1992 by Christopher Alexander.

Although Tuan seemed unconvinced of the practical effectiveness of this method and voiced philosophical critiques on the non-evolving and value-laden nature of "requirements: he endorsed the potential of Alexander's logico-mathematical process to elucidate "without undue arbitrariness" and "in concrete patterns" the "realities of modern life" (1964a: 14). Tuan's remarks against "arbitrariness" moderately echoed Alexander's polemical introduction to the *Notes*, in which he announced a "loss of innocence" (1964b: 8) and urged for the "need for rationality" (1964b: I). "Rationality," Alexander suggested and Tuan repeated, would safeguard designers from resorting to "unexamined preferences" (Tuan 1964: 12), inherited conventions, and the excuse of "intuition" (Alexander 1964b: 2) when faced with ever-changing design "problems" of mind-boggling complexity (Alexander 1964b: 3).

Several scholars have linked early conversations about computers and architecture with debates on the place and form of "rationality" in a modern architectural discipline (for example, Dutta 2013, Halpern 2015). Alexander has also been recognized as one of these debates' key instigators (for example, Broadbent 1988 [1973]: 273; Bruegmann 1989: 141, 146). Alexander put forward a particular mode of calculative rationality consisting of rule-based operations. His method of hierarchically decomposing design "problems" was taken up by several architects and planners in the United Kingdom and North America, who adapted it for pedagogical experiments or developed computer variations of its first digital computer implementation in MIT's Computation Centre IBM 709 machine. With Alexander being among the first architects to engage with the development of a logico-mathematical formalism for design, the *Notes* came to symbolize a pursuit for rigor and a research ethos that burgeoned in Anglo-American architecture schools throughout the 1960s under the broad and interdisciplinary umbrella of "rational theories and methods" of design (Moore 1966: 1). Despite Alexander's disavowal of design methods in the mid-1960s (Alexander 1971: 3), the *Notes* remained, as architect and urbanist Roger Montgomery would later write in *Architectural Forum*, the "first manifesto" of a "worldwide movement" to "modernize design methods and bring scientific rigor into their [the designers'] ancient craft" (1970: 52).

This essay aspires to disentangle and historically contextualize dimensions of Alexander's influential call for "rationality," all the while contributing a productively distinct case in a growing body of scholarship detailing episodes of this hazy slogan's postwar "career" (Erickson et al. 2015). Drawing primarily from progress reports and correspondence found in the archives of Alexander's doctoral advisor, Russian émigré architect Serge Chermayeff, I follow the making of Alexander's design theory from his enrolment at Harvard in 1958 to the launch of the *Notes* in 1964. I pay special attention to the epistemic cultures (Knorr-Cetina 1999) and technical languages that Alexander engaged, and to their relationship with various symbolic meanings and operational embodiments of "rationality" in his work. Specifically, I identify two distinct concerns entangled with his plea for "rationality:" one pertaining to decision-making and one to the organization of empirical data. I discuss how the mathematical device of the "tree" melted and molded both of these concerns into a single structural abstraction of the at once *problem*, *process*, and *outcome (form)* of design. To accounts of import of ideas from cybernetics, linear programming, and decision theory (Upitis 2008; Steenson 2017) into architecture, I juxtapose a story of *translations* of architectural concerns emanating from realities of postwar industrial housing into a mathematical language.

I further argue that the specific mathematics that Alexander used, namely graph theory, enabled him to pursue a reconciliation between rule-based rationality and its perceived opposite, intuition. As Tuan remarked in his *Notes* review: "The logical structure does not prescribe [physical] form; but it does express pattern, order and relations which can then be translated, through processes still largely intuitive, into an orderly complex of forms" (1964: 12). Alexander attacked but did not ostracize intuition. Instead he delegated subjective judgment *on top of* an objective mathematical substrate—a scheme that, I will argue, propelled a specific imagination for the place of computers in design processes. This chapter describes an episode in the construction of common grounds among architecture, mathematics, and computers at the nexus of multiple epistemic communities and technical languages. More than that though, it tells a story of the co-construction of a particular image of "rationality," one inextricably linked with the mathematical technique enlisted to deliver it.

The need for choice

With a psychoanalytic undertone, biographers and scholars of Alexander's work have persistently repeated the anecdote of a dismayed father seeing his mathematical prodigy son choosing the "disreputable" and "idiotic" (Grabow 1983: 299) career path of architecture instead of a properly "scientific" field. They have also repeated Alexander's fast and forceful disillusionment with the uncoordinated, nonsensical, and "absurd" (Grabow 1983: 31) status of architectural education, soon after joining the Architecture Department at the University of Cambridge in 1953. Self-taught in aesthetic theory, with two years of intensive mathematical training at the Trinity College, and carrying strong opinions about the architectural discipline, Alexander contemplated the next step. After rejecting a PhD in aesthetics under the supervision of logical positivist philosopher Alfred Jules Ayer and a post in the London Building Research Station, Alexander joined one of the emerging epicenters of postwar modern architecture: the Harvard Graduate School of Design (GSD).

When Alexander arrived at the Harvard GSD in 1958, the School was still reverberating with echoes of Bauhaus founder Walter Gropius's 15-year chairmanship, and the function-oriented, technology-driven, interdisciplinary, and future-centric architectural ethos that he had installed. Alexander's enrolment at the GSD also occurred in the context of a growing "urban design" agenda, the term denoting a middle ground between large-scale planning and micro-scale residential interventions. This agenda was being promoted by Gropius's successor Josep Lluís Sert, GSD Dean of the school since 1953 and formerly president of the International Congresses of Modern Architecture (CIAM). One of the Bauhaus' and the CIAM's key characteristics was the espousal of "rational" architecture as a key pillar of their modern agenda. Rationality was a central moral ideal in the *longue durée* of Western architectural theory that prioritized functional or material economy over other considerations and sanctioned reason as the basis of design.

Alexander would mold such values of rational architecture with a distinctive chapter of American intellectual history that scholars have labeled "Cold War rationality" (Erickson et al. 2015). This mode of rationality has been historicized as emanating from US government agencies and decision-making organizations, ultimately trickling down to the hallways of academic departments. "Cold War rationality" was mistrusting of human reason and judgment, with a proclivity for rule-based, universalizing, abstract, and possibly mechanizable operations (Erickson et al. 2015: 2). It was the kind of rationality that elevated mechanical rules to an intellectual virtue, enabling the imagination of computers as superior makers of decisions and performers of operations traditionally delegated to human deliberation (Erickson et al. 2015: 4). Arguably, Alexander's *Notes* sits squarely within this intellectual phenomenon, from both a methodological and a rhetorical perspective. His polemic against "intuition" and "arbitrariness," along with his logico-mathematical rendition of design, cast him as one of the many interlocutors of this particular postwar genre of rationality. It may come as a surprise then that Alexander's trajectory toward the *Notes* began with a call different than, and actually resisting, the book's opening motto. In one of his first PhD progress reports, dated September 1958, Alexander advocated for the "need for choice" as a corrective to an over-reliance to "logic and rationality" (Alexander 1958a: 1).

The progress report opened with a telegraphic synopsis of his proposal: "A conceptual model for the design process. Particular problems of prefabrication and technology. The American house" (Alexander 1958a: 1). Following this curt summary was a list of "men at Harvard" (Alexander 1958a: 1) with whom Alexander had established contact upon his arrival at the University. The list featured his soon-to-be doctoral committee members Serge Chermayeff and Jerome Bruner. Bruner was an eminent American cognitive psychologist who would establish, two years later, the Harvard Center for Cognitive Studies and employ Alexander as a research associate (Grabow 1983: 193). It also included gestalt psychologist Hans Wallach and Harvard professor Martin Meyerson, future founder of the MIT-Harvard Joint Center for Urban Studies where Alexander would also find a research home.

The September 1958 report, however, did not dwell on interactions with these figures, who would come to be decisive influences on Alexander's trajectory. Instead, it focused on two under-discussed actors: Vienna-trained art historian Eduard Sekler and applied mathematician and mathematical psychology pioneer R. Duncan Luce. Alexander reported having consulted with Luce on the possibility of using an IBM machine to plot "utility functions for various domains of decision [in a design process]" (Alexander 1958a: 1). "Utility" was a key term in rational choice theory and game theory, measuring the satisfaction of different stakeholders for a given decision in the context of a decision-making process. However, Alexander declared his mistrust of the results of such a computer model, which were contingent on the choice of "premises" (Alexander 1958a: 1)—the starting statements on which logical operations would be applied. The preoccupation with "premises" in the context of logical inference was cultivated in Seckler's Harvard seminar on art criticism, for which Alexander wrote a paper that "deplored the use of abstract phraseology in architectural writing" (Alexander 1958a: 1).

Alexander argued that the *choice* of premises and the *choice* of the conceptual model were unavoidably "arbitrary" (Alexander 1958a: 1) and that logic could only be applied after these arbitrary choices are made. "Logic and rationality cannot help you to avoid fundamental decisions… the choice of premises is up to the architect, not dictated by logic" (Alexander 1958a: 1). This realization, he argued, would impel a fresh re-examination of architectural conventions. The focus, Alexander appeared to argue, would be shifted from reasoning on the basis of logical-sounding statements and pervasive truisms about architecture to explicit, and mathematically examinable, "choices" and "decisions."

As historian Avigail Sachs has highlighted, rejecting conventions in quest for proven knowledge (2009: 54) was a dominant trope in the multivalent phenomenon of postwar "architectural research"—a key phrase broadly standing for any kind of systematic inquiry aspiring to produce generally applicable knowledge. Replacing unquestioned premises with explicit and mathematically modelable "decisions" aligned with a culture of "re-examining fundamentals freshly and fearlessly," as US architectural research spokesperson Walter Taylor had put it in the late 1940s (1947: 18). Alexander's "need for choice" is not to be mistaken for an embrace of arbitrariness as an epistemic virtue. It was instead an argument for redirecting the use of logic from the justification of general truths and values about architectural design, to the *processing* of factual information, whatever these would be. This reflected the realities of postwar architectural research in a significant way.

While still in the UK, Alexander had come into contact with the Building Research Station (BRS). This was one of several research agencies that engaged in a vast and multidisciplinary project of collecting information on the production of buildings and the needs of their inhabitants in the context of British postwar urban reconstruction. In the US, agencies operating under the 1949 Housing Act had similarly initiated wide-ranging research into technical and social aspects of housing. These inquiries brought together different specialties and confronted architects with a kind of information-based collaborative work. Aside from raising questions about architects' professional roles, languages, and tropes, this work also brought about the realization that housing stood in the cross-hairs of an ocean of requirements—conflicting needs, values, and preferences.

In a draft to Chermayeff, Alexander called these requirements "form-determinants." "Form-determinants" included both the public needs collected through extensive empirical work and the designers' aesthetic preferences or other ideals. Alexander framed this polyphony of "form-determinants" as a corrective to the dominance of singular arbitrary ideals such as "beauty," "social status," "structure," "taste," "economics," "function," and "social structure" (Alexander n.d.-c). The Programming of Design Decisions: 1–2). Alexander's first response to the negotiation of the often irreconcilable tension between form-determinants was a *game*.

A cooperative game

In an October 1958 progress report, Alexander described his dissertation as "formulation of [a] mass-produced house design procedure as a cooperative game between architect and society" (Alexander 1958b: 1). This game would help safeguard the architect's role as "reformer," "form giver," and teacher of "visual sophistication" (Alexander 1958b: 1, 2) against an increasingly wary public. Alexander proposed deploying a game-theoretic formalism, on which the report did not elaborate, as the mathematical core of a new design process consisting of the following steps: first, collection of information about public needs (requirements) through questionnaires or interviews; second, use of this information to design an ideal physical form as seen from the architect's perspective; third, field work to gauge the public's reactions to the architect's ideal form and use of the game-theoretic formalism to negotiate choices; and finally, mutual settlement to "a balanced solution" (Alexander 1958b: 2).

The degree of Luce's influence on Alexander is difficult to assess, but it is productive to contemplate intellectual and technical parallels between the development of Alexander's thinking and Luce's landmark publication *Games and Decisions* (Luce and Raiffa 1957). *Games and Decisions* was a seminal text in game theory, with exceptional appeal for psychologists and social scientists, that brought mathematical models for decision-making and social negotiation into the human sciences. Graph theory was a prominent technique in the book, used to represent a game (the so-called "game tree"), possible moves at each step, and decisions made in the process. A few years earlier, Luce had published in the *American Journal of Mathematics* two theorems for decomposing a group of entities linked by relationships (1952). The mathematical problem of dividing a graph into sub-graphs based on some property of the relationships between its points, could be readily applied in the study of social groups. Graphs and decomposition would come to be key devices in Alexander's future mathematical repertoire.

Applying game theory to design would not only balance conflicting requirements, achieving a happy medium between the architects' and the public's priorities, but would also offer architects a way of staying afloat in an ocean of information. Alexander argued that despite efforts to "educate designers in this total grasp of form-building," the only good architecture was produced by a "few men of genius" able to "to have a grasp of everything that matters" (Alexander n.d.-c. The Programming of Design Decisions: 2). A growing and unwieldy body of "technical information" "handicapped" even these "freaks of genius" and resisted "intuitive" absorption and apprehension (Alexander n.d.-c. The Programming of Design Decisions: 2). The game would enable rational decision-making in a situation that hampered judgment and turned old ways of reasoning defunct. In *Notes* Alexander would paint a similar picture of architects' ominous predicament. "Bewildered," he lamented, "the form-giver stands alone" (Alexander 1964b: 4).

In their working group book on Cold War Rationality, Erickson, Klein, Daston, Lemov, Sturm and Gordin have argued that the calculative rationality of postwar US flourished in the affectively charged context of threats so grave and stakes so great that could overwhelm human psyche and incapacitated reasoning capabilities (2015: 1). In this context, mechanical, mathematical calculations were seen as a refuge from panic-induced errors in judgment. Alexander's invocation of games and mathematical theories of decision-making in the face of inundating amounts of information collected through building research strikes a similar tone. Apart from decision-making errors, unmanageably large bodies of information posed an additional threat: disorder and confusion. Without a classificatory scheme, Alexander worried that the information for various "form-determinants" would "dissolve into chaos" (Alexander n.d.-b. The Design of the Urban House and Ways of Clustering It: 6). Alexander's research would soon be transposed into finding a way of disciplining information into a neat image comprehensible at first sight.

A logical structure

From 1959 and on, Chermayeff's archives include research proposals and research progress reports jointly written with Alexander. These projects culminated with the co-publication of the influential *Community and Privacy: Toward a New Architecture of Humanism* (Chermayeff and Alexander 1962). The book conceptualized urban organization as a hierarchy of components and subcomponents and presented a method, similar to the one Alexander detailed in *Notes*, for designing such components to account for various "pressures" (the rough equivalent of form-determinants). The final step was combining these components to produce urban complexes with well-ordered hierarchies. In a June 1965 letter to Chermayeff, Alexander characterized his role in the collaboration as elucidating Chermayeff's thoughts. "When we worked together in Cambridge," Alexander wrote, "part of the little help I was to you, came from the fact that I tried to re-state, more clearly, your own thoughts as you saw them" (1965a). This "clarifying" work opened a new set of concerns for Alexander, who shifted his focus from game theory to problems of classification and information storage and retrieval.

Alexander and Chermayeff's collaboration capitalized on the financial, intellectual, and technical infrastructure of the Harvard-MIT Joint Center for Urban Studies, a university-affiliated interdisciplinary research center founded by Martin Meyerson and MIT professor Lloyd Rodwin in 1959 with funding from the Ford Foundation. Alexander was employed in the Joint Center from 1959–1960. There, he worked with Chermayeff on a research project called "The Urban House." The project was the offspring of an effort initiated in one of Chermayeff's Harvard seminars in 1952 and revisited in 1956 and 1959, to identify "a vocabulary capable of describing the infinite variety of elements, situations, activities, or events that make up the complex organism 'house'" (Chermayeff and Alexander 1962: 152).

This endeavor was not a first. Chermayeff's efforts aligned with attempts to classify architectural and urban components in different scales, not only as a way to organize empirical information collected by research agencies, but also as a theoretical problem. Broadly, the problem pertained to the fundamental categories for thinking about architecture and the city in the face of industrialization and accelerating technological change. Among the most influential efforts in this direction was Knud Lönberg-Holm and Theodore Larson's *Development Index* (1953), which, in the authors' words, sought to "outline the various series of factors involved in development relationships" (1953: Index Development). "Development" here stood for a continual assessment of technological change and the new human needs these instigated, and its transformation into new "patterns of activity" (Lönberg-Holm and Larson, 1953: Ia. Development Goals).

Alexander had become aware of Lönberg-Holm's classification scheme while thinking about how to organize the "factual data" collected in the empirical research part of his proposed design process, but dismissed them as "a little awry" (Alexander n.d.-b. The Design of the Urban House and Ways of Clustering It: 6). A nagging sense of arbitrariness also permeated Alexander's attempts to develop other systems of classification. It was not long before he identified the source of his discontent. In 1960, he wrote to Chermayeff that his previous explorations in categories of components had, in fact, been irrational. "Though I had been talking a great deal about logic," Alexander admitted, "I had not yet used it, put it to work" (1960b: 1). After perusing questions of information storage and retrieval and conferencing with IBM research team members, he realized that the categories he was looking for lay in the *information itself*. The classification logic was intrinsic to the set of requirements (the design "problem"). Alexander wrote:

> The practical problem immediately confronting us is to isolate groups of 'failures', areas for research, so that within each one of these limited areas the design problem becomes manageable.
>
> What we had been trying to do was to isolate these groups "by eye" so to speak: a priori; and this is what was wrong.
>
> I realized that the groups were actually given by the logic of the relations tying our failures to one another—if one only knew how to look for them. And that if we could set the system up suitably, the logic would allow us to extract the groups of failures we wanted, quite NON-ARBITRARILY.
>
> (1960b: 1)

"Failure" was the precursor of "misfit," a central concept in the *Notes*. It denoted a kind of physical condition that prevented a need from being satisfied (for example, sleep prevented by bioclimatic discomfort). Because of their definition as physical conditions, "failures" not only established relationships between requirements and aspects of physical form, but also established "linkages" (Alexander 1960a: 2) between the requirements themselves that Alexander would call "interactions."

Sometimes failures shared data, other times they were corrected by the same operations, and other times the correction of one failure aggravated

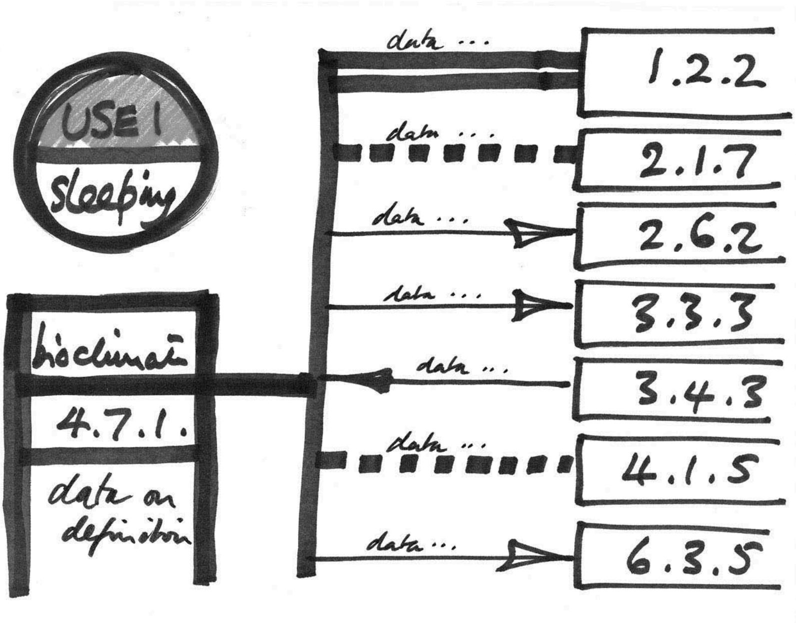

Figure 4.2 Sketch of a failure card by Christopher Alexander. Source: Alexander, C. 1960a. Letter to Chermayeff Re: Failure Cards. [document]. Box 4, Folder "Alexander, Christopher, 1958–1966," Serge Ivan Chermayeff Architectural Records and Papers, 1909–1980. Dept. of Drawings & Archives, Avery Architectural and Fine Arts Library, Columbia University.

the other. Similar relations of overlap, reinforcement, or conflict were then established among the failures' corresponding requirements. By considering "the relations themselves, or links" between failures, it would be possible to achieve Chermayeff and Alexander's main deliverable: "a working programme for design" (Alexander 1959a: 2).

Program, for Alexander, was both structural and procedural: structural, because it represented a logical organization of design requirements and procedural, because it indicated the order by which the designer should address these requirements. The step-wise decision-making rationality cultivated through Alexander's game theoretic interests aligned with the representational ideal of well-ordered, intelligible data developed during his Joint Center appointment. The mathematical device that would enable the collapse of process into structure was, as Alexander first announced in 1961, the "topological 1-complex" or, more simply, the linear graph (Alexander 1962: 117).

The image of rationality

After completing his research appointment at the Joint Center, Alexander requested $166,000 from the US Building Research Institute (BRI) to pursue a three-year experiment on the means and effects of correlating information about building with a specific design "problem." His proposal, titled "Information and an Organized Process of Design," was presented in the Spring 1961 *New Building Research* Conference of the BRI Division of Engineering and Industrial Research. Since 1956, the BRI had been publishing a comprehensive guide listing "sources of information on research and technical developments in the industry" (Building Research Institute 1962: 172) with quarterly supplements and annual indexing. This raised the challenge of documenting building science literature effectively and efficiently, ultimately becoming the theme of the fall 1959 BRI conference. The event featured seminal librarians and information specialists, such as coordinate indexing inventor Mortimer Taube.

The problem posed by the BRI, or at least the way that Alexander interpreted it, had to do with developing a proper organization (structure) on which the abundant knowledge and data about building that were becoming available would be able to hang from. This was a concern that had preoccupied a good portion of his doctoral work. To the arbitrary matching between the organization of building information and the needs of a specific design situation, Alexander counter-proposed "to set up temporary isomorphisms between the library's organization and the cognitive organization of the process" (Alexander 1962: 120). "Isomorphism" etymologically translated as equality of form, was a mathematical term indicating a one-to-one mapping between the elements of two different systems. Achieving Alexander's goal necessitated "some logical or mathematical relation between the two classification systems," the source of which would be "the topological structure of the problem" (Alexander 1962: 120).

In his BRI proposal, Alexander presented one page with five mathematical figures (Figure 4.3). The first figure was an entanglement of straight lines, connecting multiple points (nodes) (Alexander 1962: 118). Alexander explained that the figures were graphs, whose points represented the requirements that compromised the so-called "design problem." The graphs' lines represented "interactions" among requirements. Alexander continued to suggest that the problem's logical structure became *visible* by considering conflicting relationships between its constituent units (the requirements). These conflicts were mathematically translated into relations that bound different requirements together and helped identify the problem's "functional units"—subsystems of strongly connected requirements that could be handled separately from other requirements. The second and third figure showed a transformation of part of the first figure's graph into sub-graphs that revealed the subsystems emerging from the consideration of interactions among tangled and disordered requirements. Alexander annotated the second and third figures with hand-drawn

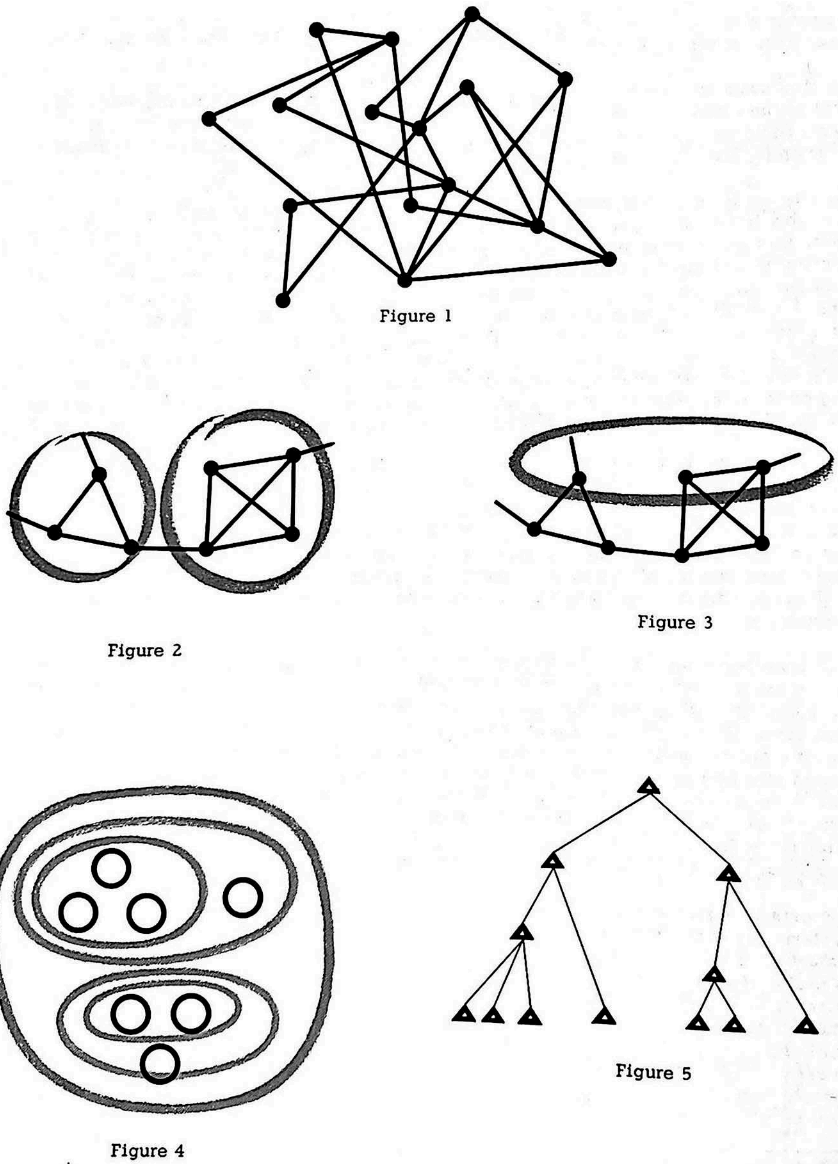

Figure 4.3 A graph drawn in a disordered way transformed into a hierarchical tree. Source: Alexander, C. 1961. Information and an Organized Process of Design: A Research Project Proposal. [document] Center for Environmental Structure Archive.

circles, which in the second figure indicated the two independent functional units, and in the third figure, an "arbitrary" functional unit or category that designers traditionally used. The difference between the second and third figures was that the former's subsystems were sanctioned by mathematical analysis while the latter relied on conventions that did not survive mathematical scrutiny.

Pointing to the fourth and fifth figures, Alexander further proposed that the "nested" subsets ("system of systems within systems" (Alexander 1962: 119)) could be redrawn so as to "bring out its hierarchical form more obviously" and that the resulting "picture" "look[ed] like a tree" (Alexander 1962: 119). "This tree," he added, "really *prescribes the process of design* [emphasis mine]. You start at the bottom, solving the simplest systems of requirements, and work your way to the top" (Alexander 1962: 119).

Computer architecture

The mathematical calculations for deriving the design "program" were automatable by a digital computer. While employed in the Joint Center, Alexander had already started taking first steps toward programming an IBM 709 machine to automatically produce design "programs." During a consultancy at the Civil Engineering Systems Laboratory from 1960–1962, Alexander developed the first fully functioning version of such a system in collaboration with civil engineer Marvin L. Manheim. The computer system, called HIerarchical DEcomposition System 2 or HIDECS 2, would gain Alexander the reputation of a computer frontiersman in architecture. Alexander used the computer to perform a rote process: making trial cuts of an initial unordered graph (the set of requirements) into subgraphs, calculating an "INFO" parameter based on the number of links that the partition cut and the number of vertices at each side of the partition, and performing a heuristic optimization method to minimize the parameter. Minimizing INFO would mean minimizing interdependence between the groups partitioned by the system at each step.

In March 1962, Alexander and Manheim circulated a research report documenting how the design "programs" (trees) outputted by HIDECS 2 could be used in the context of an actual design situation: in this case locating a section of the I-91 Interstate Highway System in Western Massachusetts along a 20 x 10 mile area of the Connecticut River valley. This "demonstration project" meant to "to illustrate certain aspects of a new approach to physical design problems" (Alexander and Manheim 1962b: 1). In the context of highway route location, diagrams were simply "lines and areas on a map" (Alexander and Manheim 1962b: 1). Alexander and Manheim identified 26 location requirements and set out to develop diagrams based on calculations of "utility" of various highway positions from the standpoint of each requirement. Unable to calculate the utility of lines, they drew the diagrams using points, with black being the most favorable and white the least favorable. The process resulted in 26 diagrams, or "utility maps" (Alexander and Manheim 1962b: 112), each of which corresponded to one of the "problem's" requirements and was to be combined based on the HIDECS 2-outputted tree.

The synthesis proved exacting. Each map represented potentially incommensurable utility functions. Furthermore, a simple addition of utility per point did not account for the properties of a highway as a whole (Alexander and Manheim 1962b: 91–92). "Even if we combine the 26 diagrams in the order which the tree prescribes," the authors pointed out, "we shall still always hit the same resist if we do no more than add them; we shall *still not overcome the objections to straightforward combinations* [emphasis mine]" (Alexander and Manheim 1962b: 91–92). Although the HIDECS 2 analysis was automatic, the synthesis required seeing and judgment. Alexander and Manheim superimposed the diagrams photographically, projected them on a drawing board, and then sketched over the projection to identify desirable areas in terms of utility, while preserving what they described as the configurational characteristics (a plausible shape) for the highway. HIDECS 2 needed a special supplement that was none other than the designer's eye. Alexander and Manheim wrote:

> While it may be possible in principle to deal with these matters analytically and program them for digital computers, in practice, present digital computer techniques and utility theory are too little advanced to be of much use. [...] Of course people have used their eyes and heads before. But the idea that the human eye is a special purpose computer for solving problems of this type, shows us the process outlined as a framework in which the computer can be used intelligently and efficiently.
>
> (1962b: 117)

It was not the eye-as-computer metaphor that is remarkable here—this was a pervasive metaphor in the cognitive psychology circles that Alexander was part of during his doctoral studies. Rather, it was the idea that humans and digital computers could have complementary roles; that mechanical logico-mathematical rationality did not exclude, but rather called for the intuitions of the human eye. The designer's judgment was never eradicated from Alexander's process: it was instead displaced as the epiphenomenon of a logical structure.

In sketching out his research project, Alexander had written in 1959: "In many kinds of research the findings lead straight to the answer—given the findings, the result is completely determined. In our research this will not be the case. The design [underlined in the original] comes from the designer" (1959b: 1). The HIDECS 2 decomposition method, which made it into Alexander's dissertation and ultimately into *Notes* with minimal modifications, was analytical and largely mechanical. The computer's job was outputting the "problem's" "logical structure" and a step-wise decision-making process for attacking it.

With the paralyzing data inundation on "requirements" disciplined through rational analysis, with the "bewilderment" cured, designers could exert intuition without risk of errors and slips of judgment. Intuition, preferences and other notorious antonyms to rationality were permissible in the development of the "diagrams" and their hierarchical combination to form "composite diagrams." This combination would be frictionless, as the tree's subgroups' independence would ensure that no "conflicts" among requirements would arise. More crucially though, combining diagrams in the process designated by the tree would establish a one-to-one match between the structure of the design problem and the structure of the physical form. "The hierarchical composition of these diagrams," Alexander wrote in closing to the *Notes*, "will then lead to a physical object whose structural hierarchy is the exact counterpart of the functional hierarchy established during the analysis of the problem" (Alexander 1964b: 131). Analysis and synthesis, decomposition and realization would be isomorphic, with the common skeletal vision of the tree.

The particular mode of "rationality" that Alexander vouched for in the *Notes* introduction cannot be severed from the mathematical object of the tree. A visual shorthand for Alexander's theory, the tree clearly placed geometric shape—visual, aesthetic, intuitive—on top of an abstract structure derived through logico-mathematical operations. This protocol also applied to the roles of humans and digital computers: the former operating within the bounds set by the latter. The I-91 superimposition of "utility maps" was the closest to this protocol being subverted, as the fusion of diagrams by eye and hand blurred their discrete identities and destabilized the categories of analysis. Yet, the use of diagrams in other architectural and urban design examples that Alexander presented remained limited to a building-block model of combination—a telling example being the *Notes*' famous appendix, showing an implementation of HIDECS 2 to derive a master plan for a village of six hundred people in Gujarat, India (Alexander 1962, 1964b).

As I have argued elsewhere, a similar discrete logic and a preoccupation with an invariant structure underlying physical form, or the built environment as a whole, characterized Alexander's post-*Notes* expeditions at the University of California Berkeley (Vardouli 2017). Despite Alexander's correctives to the tree's hierarchical nature, his disavowal of stringent logico-mathematical methods and his professed embrace of intuition and "feeling," his theories never escaped the belief that shape is underpinned by a mathematically knowable abstract structure that precedes and generates it.

Apart from haunting Alexander's trajectory, the scheme of intuition *on top of* logic, shape *on top of* structure, empirical *on top* of abstract, and human *on top of* computer, is productive for critically contemplating the proliferating and ever-bifurcating relationships between computers and architecture. The phantasmagoria of graphics-rich screens and fluidity of computer interfaces evokes a different atmosphere than mathematical formulas and precise calculations. Yet, although these are hidden from view, they are far from absent. In their majority, contemporary computer aided design and drafting applications cast geometric appearance on top of logical operations and mathematical calculations. Computers tame perceptual appearance as the epiphenomenon of logical structures. Recognizing this relationship and its intertwining with historically specific architectural cultures can open alternative imaginations for computer architectures.

Conclusion

Looping back to the start, "Notes on Computer Architecture" was not about the new technological artifact of the digital computer and its promises, or threats, for the architectural profession. Aside from advertising it in the title, Tuan did not mention the word "computer" once in his review. "Computer architecture" appeared to be less about new instruments performing old processes, and more so about conjuring up new theories of process—an argument that Alexander would famously make himself in his influential paper "A Much Asked Question About Computers in Design" (1964a).

In this essay, I took Tuan's decentering of the computer as a methodological heuristic to perform a sketch of a decentered history of computer architecture. Moving the technological artifact of the computer off centre suggests an opening to other histories of computer architecture that speak not of tools but of *translations*—translations of architectural concepts and operations in logico-mathematical terms. This expands the conversation toward the material contexts and knowledge settings of these translations, alongside their cultural commitments, epistemic proclivities, and disciplinary aspirations. My goal in this essay has been to open a seemingly a-contextual and logically complete formalism to historical scrutiny and examine the ways in which it constructs and is constructed by ideas of "rationality."

This essay is not the first to scrutinize the making of Alexander's *Notes*. Alise Upitis has made a strong materialist argument about the determination of the *Notes* method from the practical constraints of programming an IBM computer ca. 1960 (2013). While adopting a similar sensibility that design formalisms are historical artifacts, contingent on the contexts in which they were developed, this essay positions their construction in the middle ground between epistemic cultural tropes and work with particular instruments and techniques. Although the tree's programmability in an IBM machine was plausibly an important force for establishing the tree as the response to Alexander's quest for "rationality," it was not the only one. By following Alexander's pursuit of this misty concept, I shed light on the tree's entanglements with games and decisions, with issues of information organization, and with ideas about architectural and urban hierarchies, all the while relating these conversations to broader anxieties and realities of postwar modern architecture.

Instead of distilling one definition of Alexander's "rationality," this essay has further untwined the term, arguing that the nebula surrounding it was precisely its appeal. I have portrayed a rationality in flux that only temporarily settled into a definition, only to bring into play certain techniques that would shift its shape and meaning. I have also hinted at the critical implications of coupling catchphrases that animated postwar architectural research with their operational definitions, and of developing a discourse at the interface of rhetoric and technique. As logical and mathematical techniques lurk at the backdrop of our computer screens, it is time to tell their stories.

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