Nexus Network Journal (2019) 21:591–622
https://doi.org/10.1007/s00004-019-00441-8

NEXUS NETWORK JOURNAL
Architecture and Mathematics

RESEARCH

The Dirksen Grammar: A Generative Description of Mies van der Rohe's Courthouse Design Language

James Park[1] **· Athanassios Economou**[1]

Published online: 2 July 2019

Abstract
A generative description of Mies van der Rohe's courthouse design language is presented in the form of a three-dimensional parametric shape grammar and its significance in the discourse of courthouse building type is discussed.

Keywords Generative description · Shape grammars · Courthouse design · Courthouse building type · Ring morphology · Mies van der Rohe · Everett McKinley Dirksen United States Courthouse · Design Excellence Program

Introduction

> For architects one of the greatest challenges continues to be how to make the most complicated of building types with its multitudes of circulation routes comprehensible to users and how to render a secret building a legible one. Experimentation with rendering the insides of the building visible gets to the heart of contemporary debates about public space and the democratic deficit (Mulcahy 2011: 160).

Courthouses pose unique design challenges. They have complex functional and symbolic requirements and vary extensively in size, volume, configuration, form, program and style. The courthouse design has received lots of attention in the past few decades under the Design Excellence Program administered by the United States General Services Administration (GSA). The program has fostered numerous innovative courthouse designs and a growing number of scholarly works on this topic (Byard 2006; Greene 2006; Gruzen et al. 2006; Leers 2006; Phillips

✉ James Park
james.park@gatech.edu

Athanassios Economou
economou@gatech.edu

1 College of Design, Georgia Institute of Technology, 245 Fourth Street NW, Atlanta, GA 30332, USA

2006; Phillips et al. 2003; Resnik and Curtis 2011; Seale 2006; Woodlock 2006). Perhaps the most telling characteristic of the architecture of the courthouse is its recursive form. A courthouse is essentially like a matryoshka doll consisting of three entirely independent buildings built into one: an honorific building that consists of courtrooms and their associated spaces including public spaces, jury spaces and attorney and witness spaces; a quotidian building that consists of all administrative spaces ranging from a cluster of few offices to a vast expansion of various bureaucratic spaces; and an incarceration building that consists of the spaces for a law-enforcement agency including a temporary jail. Each of these buildings has its own functional, spatial and circulation requirements and all of them must resolve to the complete configuration of the courtrooms where adjudications are administered.

The design of the interfaces between the three discrete buildings and the need for all to include and terminate into the various courtrooms, the literal and figurative core of the courthouse, is a complex task. The United States Courts Design Guide provides a useful account on the multiplex functional and adjacency requirements of the courthouse design specified in terms of three zones, namely, (a) public, (b) restricted and (c) secure zones (Administrative Office of the United States Courts 2007). The public zone includes an entrance lobby, waiting areas, attorney and witness rooms, restrooms, as well as circulation corridors, staircases and elevators; the restricted zone includes judge's chambers, clerk's offices, probation and pretrial offices, court libraries, jury suites, restrooms, mechanical spaces, storage spaces, maintenance closets, as well as circulation corridors, staircases and elevators; and the secure zone includes offices for the United States Marshals Service, temporary holding cells, as well as circulation corridors, staircases and elevators.

Solutions to the conundrum—the design of three closed networks that do not interact with one another and the design of three coherent but distinct zones within the buildings that need to interact in specific ways—cannot be achieved easily. Among the various solutions that have appeared in the literature, the most ubiquitous morphological solution to this problem is provided by the ring morphology (Mulcahy 2011). From its genesis at Waterhouse's revolutionary rethinking of the courthouse building type in his 1864 Manchester Assize Courts in the UK to its formal consolidation in Mies Van der Rohe's pristine Everett McKinley Dirksen United States Courthouse in 1964 in the US, the ring has emerged as the most significant morphological element that organizes the functions and defines the form of the building type. The work presented here undertakes the Dirksen Courthouse as the definitive conclusion of this configurational morphology and discusses in depth its elements and relations to characterize its generative power and legacy in the future of courthouse design.

The Dirksen Courthouse is one of the most significant buildings of Mies squarely belonging in the mature phase of the architect's work. Significantly, it is the only courthouse that Mies ever designed and provides the sole window towards his language and vision of courthouse design at large. Furthermore, the design process of the courthouse schematics has been survived and it is amply documented in the Mies van der Rohe Archive at the Museum of Modern Art New York (Mies van der Rohe et al. 1992). The documentation of the design process consists of 135 sketches produced by the office of Mies and provides an incredible insight into the thought process and the formal speculations worked out in the office. Site plans, ground floor plans, courtroom floor plans, sections and elevations, all illustrate slight or significant variations of the final design and provide a body of work that suggests a much richer palette of configurational possibilities. The emergent configurational types and the unique design variations within each type suggest that the iterative configurational study upon the courtroom floor plans paired with the corresponding ground floor plans was the primary means of the schematic design exploration. In this sense, the collection of courtroom floor plans provides a unique opportunity to retrace Mies' inquiry in the exploration of configurational possibilities of the core of the building, the courtroom plate.

The Dirksen grammar presented in this work is designed based upon the series of spatial relations extracted from the formal analysis of the corpus and the rules of the grammar are parametrically defined to generously encompass Mies' language and vision of courthouse design. A parametric shape grammar interpreter, GRAPE (Grasl and Economou 2013), is employed to design, implement and evaluate the grammar. The implementation of the grammar automates the generations of existing and newly emerged Miesian courthouse design variations in the forms of three-dimensional models. These design variations are systematically examined in terms of their formal and functional properties to evaluate the consistency, flexibility and potential of the grammar towards a generative theory of the courthouse design at large.

The Legacy of the Dirksen Courthouse

The Dirksen Courthouse, built in Chicago during 1959–1964, is one of the most significant buildings of Mies (Blaser 1977, 1997; Carter 1999; Cohen 1996; Lambert 2001; Progressive Architecture 1965; Spaeth 1985). It belongs in the mature phase of Mies' work and provides a classic example of his high-rise buildings along with the Seagram Building completed in 1958; the Toronto Dominion Centre completed during 1967–1969; the One IBM Plaza completed in 1970; and the Kluczynski Federal Building completed in 1974, at the same site with the courthouse, as a part of the Chicago Federal Center (Cohen 1996; Spaeth 1985). Significantly, the Dirksen Courthouse is the only courthouse that Mies ever designed and provides the sole window towards his language and vision of courthouse design (Lambert 2001). While its formal clarity and elegance are on par with the ubiquitous architectural characteristics associated with the Miesian language, the unique programming of the building distinguishes it within the corpus of the built work of the architect.

The design and construction of Mies' courthouse did not come without controversy and it has played since a significant role in the history of the courts in the US (Carter 1999). The federal buildings in the US had been supervised by the federal government since the establishment of the Office of the Supervising Architect in 1852 and until 1893, when the Tarsney Act allowed private architects to design federal buildings, laid the foundation for the establishment of courthouses as embodiments of state-of-the-art design in the public realm (Lee 2000). In the early twentieth century, highly polished federal buildings in the Beaux-Arts style were designed and built but the Great Depression in the 1930s left its mark with poorly, quickly and inexpensively executed stripped-down buildings to supply the public demand (Lee 2000). In 1949, under the Federal Property and Administrative Services Act, the GSA was formed pronouncing the resume of the pursuit of design excellence in public buildings and it is in this very background and context that Mies was selected and the Dirksen Courthouse was designed. More specifically, as GSA began to invest in the modernization of public buildings in the 1950s, Mies, one of the masters of the modernist architecture, was indeed an ideal candidate to design the new federal courthouse in Chicago and make a radical alignment to innovative contemporary design stripping away the bankrupt neo-classical and neo-renaissance imagery of the public buildings up to that day (Robinson et al. 2003). The commission was awarded in 1959 after Mies had already put in practice his architectural language exemplifying spatial flexibility, structural clarity and uncompromising attention to detail in his residential high-rise steel frame building designs in Chicago. Upon its completion in 1964, the Dirksen Courthouse received extraordinary nationwide attention (Architectural Record 1965) because of its incredible contrast with the ornate Beaux-Art one it replaced, the Chicago Federal Building designed by Henry Ives Cobb (1905–1965), a perfect example for the federal government's effort in promoting innovative architecture.

Since its completion, the Dirksen Courthouse has been renovated several times to accommodate operational and regulatory changes of the courthouse (Vanderbeke 1993). Still, these changes are immaterial for the purposes of this study as they point to a different set of concerns and they are entangled in the emergent since and still forbidding issues of security.

The Design of the Dirksen Courthouse

The Dirksen Courthouse is an integral part of the Chicago Federal Center, a major federal ensemble occupying a one-and-half-block at the Chicago Loop. The federal center consists of three buildings arranged around a 4.6-acre public urban plaza—two high-rise buildings, the 30-story Dirksen Courthouse and the 43-story Kluczynski Federal Building, and a single-story pavilion housing the United States Postal Service. The courthouse and the federal office buildings form the eastern and southern boundaries of the ensemble respectively and the post office pavilion marks the northwestern corner of the urban space. The courthouse is arranged perpendicular to the federal office building and has its wider side facing the plaza welcoming the public. The plaza itself is well-known as the exhibition space of Alexander Calder's Flamingo, 53-foot tall red steel stabile, commissioned by GSA and installed in 1974 (Robinson et al. 2003). The forms and the arrangement of the buildings are paradigmatic of Mies' platonic geometry: rectangular and square prisms, all carefully delineated and arranged one against the other setting the urban stage of the federal center.

The Dirksen Courthouse is cast in a rectangular footprint of 4:13 bays and a classically modern tripartite section with a high-story public entry lobby on the ground floor, the main body of 27 floors and a final cornice of three floors of mechanical spaces on the top. The main body itself is split into two programmatic volumes—the first consisting of 14 floors, from the second to the fifteenth floor, houses various administrative offices and the second consisting of 13 floors, from the sixteenth to the twenty-eighth floor, houses the United States Courts. The functional layout of the building follows strictly the correspondence and alignment of the structural and vertical cores of the building satisfying primarily the two very different programs in the lobby and the courtroom plate—the former addressing issues of grand scale, public orientation and urban space and the latter conditioned by the modular nature of the courtrooms and the rules pertaining to the distinct circulation networks around them. The correlation between the two systems of the public lobby and the courtroom plate is illustrated by the plans and the sections shown in Figs. 1 and 2.

The structure of the building is based on a steel framing construction method—a signature technology of Mies' office most prominently used in the Seagram Building completed in 1958, just 6 years prior to the completion of the Dirksen Courthouse (Lambert 2001). The differences between the modular relations between the two buildings are subtle: the Dirksen Courthouse follows a 28′–0″ × 28′–0″ structural module, a slight enlargement of the 27′–9″ × 27′–9″ structural module Mies used in his Seagram Building. The structural module in the Dirksen Courthouse is further subdivided into six commensurable units of spatial modules each measuring 4′–8″ × 4′–8″, again a slight enlargement from the spatial subdivision Mies tried earlier in the Seagram Building with a 4′–7½″ × 4′–7½″ spatial module. It is very probable that the slight enlargement of the structural module and the corresponding adjustment of the spatial module are related both to the commensurable division of the structural module and the proportioning and partitioning of the interior spaces and their further subdivisions into smaller modules of spatial elements, panels, tiles, furniture and so on.

The same structural and proportional ideas are explicitly expressed on the exterior of the building with the monolithic pilotis and the projecting I-beam mullions all finished with flat black graphite paint. This Miesian signature façade treatment is first found in the 860–880 Lake Shore Drive Apartments built during 1948–1951 and in all of Mies' high-rise buildings following since then. Here, the series of vertical stacks of window panels in 2:3 ratios and the continuation of the projecting I-beam mullions between them running upwards for 26 floors and a total sum of 312 feet, pronounce literally the structural integrity of the building and symbolically the magistracy of the courts. This upward force is capped with the contrasting façade treatment—a series of vertical louvers also finished with flat black graphite paint encloses the three mechanical floors at the top of the building. The interior of the building also celebrates the clarity and precision of the proportional ideas. It is most openly communicated in the public entrance lobby on the ground floor: the exposed interior columns and two elevator cores, in addition to the pilotis, complete the structural grid providing the basis for the spatial compositions of all upper floors.

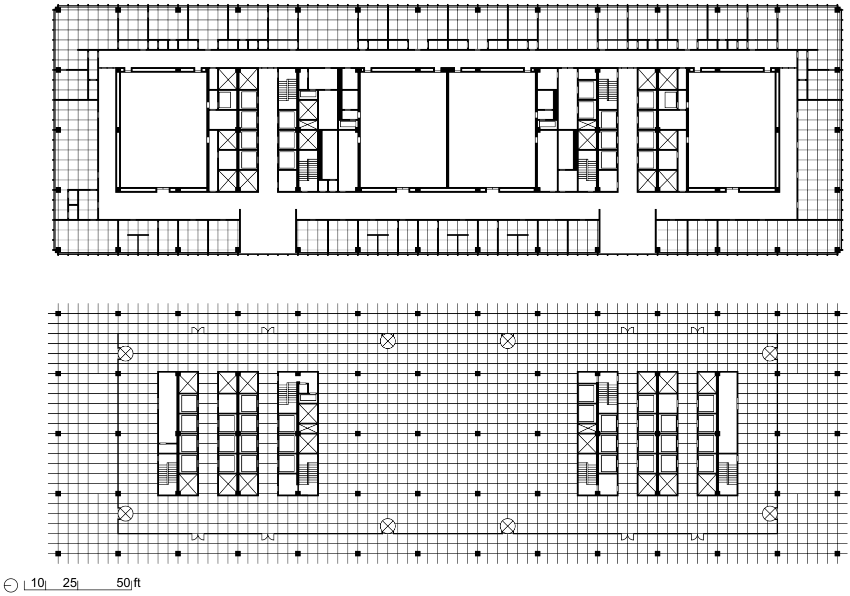


Fig. 1 Typical courtroom floor plan (above) and ground floor plan (below) of the Dirksen Courthouse (drawing by authors)

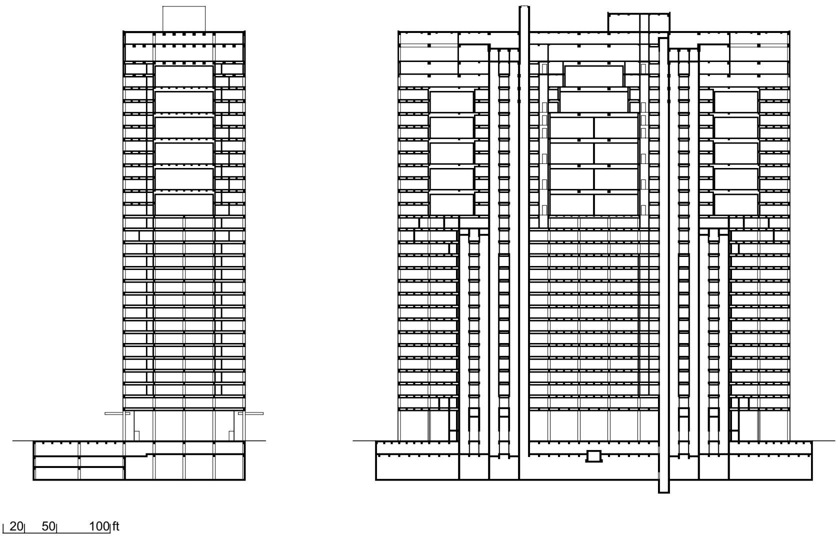


Fig. 2 Transverse section (left) and longitudinal section (right) of the Dirksen Courthouse (drawing by authors)

The Geometry of the Dirksen Courthouse

The design of the Dirksen Courthouse foregrounds one of the most important issues in courthouse design: the correlation between the courtroom plate and the public lobby plate and the ways that the highly constrained geometry of the modular courtroom plate arrangement resolves itself into the geometry of the public lobby, typically, at the ground floor. The geometry of Dirksen Courthouse's typical courtroom plate is given here in a series of eight different representations that foreground diverse geometric aspects of the plate and provide alternative insights in the formal analysis of their constituent parts: useful overviews of intersecting subsets of these representations and their usage in formal analysis and computer-aided design (CAD) implementation are given in various sources, see for example, March and Steadman (1974), Mitchell (1977, 1986) and Kalay (2004).

The schematic representation of the courtroom plate is given at the beginning of the series to provide an intermediate visual reference between the design manifested in the plan and the following representations in the series (Fig. 3a). It retains the spatial and dimensional properties of the major architectural elements—columns, structural walls and partition walls—and the openings in between them and scores the underlying Miesian structural grid of 4:13 to make explicit the relentless alignments of the architectural elements to the grid.

The gridiron representation of the courtroom plate highlights the commensurable relation of all the spaces to a given spatial module and the overall coordination of the geometries of the spaces within a regular framework (Fig. 3b). It sets forth visual analyses and privileges the proportional ideas of the modular system by providing a useful visual mapping of the proportional framework underlying the composition of the spatial elements and their relation in plan. The 4:13 bay plan is regulated by a precise proportional system that defines the structural system of the building. Each bay consists of a 28′–0″ × 28′–0″ structural square module and each is subdivided into six 4′–8″ square spatial modules that can measure all the spaces of the courtroom plate—from a square elevator core (4 spatial modules) to the 24-gon public circulation (342 spatial modules) and all commensurable polygons in between.

The regular square grid representation of the courtroom plate dissolves the visual boundaries of the spaces; instead, the sorted sets of symbols assigned to 24:78 array of cells (each cell representing 4′–8″ × 4′–8″ commensurable spatial module) describes the arrangement of the spaces more efficiently in terms of digital storage of information (Fig. 3c). This grid of commensurable units facilitated in the gridiron and regular square grid representations underlies the composition and arrangement of all spatial components of the entire building from the courtrooms (12:9 units) to the width of the public corridor (2–3 units), the horizontal division of glass enclosure on the ground floor (2 units) and the horizontal division of the façades (1 unit). Furthermore, any detail measures can be derived in terms of the unit—for example, the division of ceiling panels (2/7 unit measuring 1′–4″), which further subdivides into 1/14 unit measuring 0′–4″ and 1/28 unit measuring 0′–2″.

The dimensionless representation of solids and voids of the courtroom plate in conjunction with dimensioning vectors relinquishes the absolute dimensional measures of the spaces and encodes the binary composition of the space and poché upon a cellular structure (Fig. 3d). While the majority of the representations presented here in the series undertakes the poché as weightless boundary delineating the various spaces, this representation evokes the significance of the poché, encompassing tectonic elements, in the modeling of compendious design schematics. This specific instance of the dimensionless representation modeled upon the array of 3:4 cells is given here to maintain the visual continuity with the other representations in the series in overall proportions.

The dimensionless representation of spaces of the courtroom plate in conjunction with dimensioning vectors models each and every space of the courtroom plate in a cellular array at minimal length with respect to the overall compositional part to whole relation of the spaces (Fig. 3e). This type of representation is one of the most efficient methods of describing two-dimensional arrangements of rectilinear shapes in terms of the digital storage of information required. For example, here, the courtrooms (the sets of 7s, 12s, 13s and 18s) are described in 6:1 arrays (6 cells), instead of in 12:9 arrays (144 cells) found in the regular grid representation. It does not retain absolute dimensional properties of the spaces but the spatial relations among the spaces. This specific instance of the dimensionless representation modeled upon the array of 5:9 cells is given here to maintain the visual continuity with the other representations in the series in overall proportions.

The polygon graph representation of the courtroom plate highlights the boundary conditions of the rooms and the corridors in terms of a graph structure whose edges and nodes model the boundaries of spaces and their intersections respectively (Fig. 3f). The additional partition of the non-rectangular polygon for simplification is denoted with a set of six weighted edges (dashed lines). The ring of the courtroom plate is represented here as a set of eight rectangles—one long horizontally arranged rectangle (restricted corridor) towards the back side of the plate; one long horizontally arranged rectangle (public corridor) towards the front side; four short vertically arranged rectangles connecting the restricted and public corridors; and two rectangles (public waiting areas) in the front extending from the public corridor. Note that all of these rectangles have very diverse topologies, ranging from the expected four nodes per rectangular space all the way to 23 nodes per space.

The dual graph representation of the courtroom plate highlights the adjacency relations between the spaces in terms of a graph structure, here, the rooms and the corridors are modeled by nodes and connectivity between any given two spaces are modeled by edges (Fig. 3g). This type of representation, also known as adjacency graph, is typically useful in spatial analyses because it can model various types of relations between adjacent spaces including circulation connectivity, sound or thermal transmittance and so forth. The ring of the courtroom plate is modeled here as two nodes each denoting public and restricted corridors and they are in a one-to-many relationship with the courtrooms, offices and vertical cores.

The composite figure-ground representation of the courtroom plate models the binary composition of solids and voids along with their explicit spatial and functional properties (Fig. 3h). It is useful in designing a comprehensive architectural

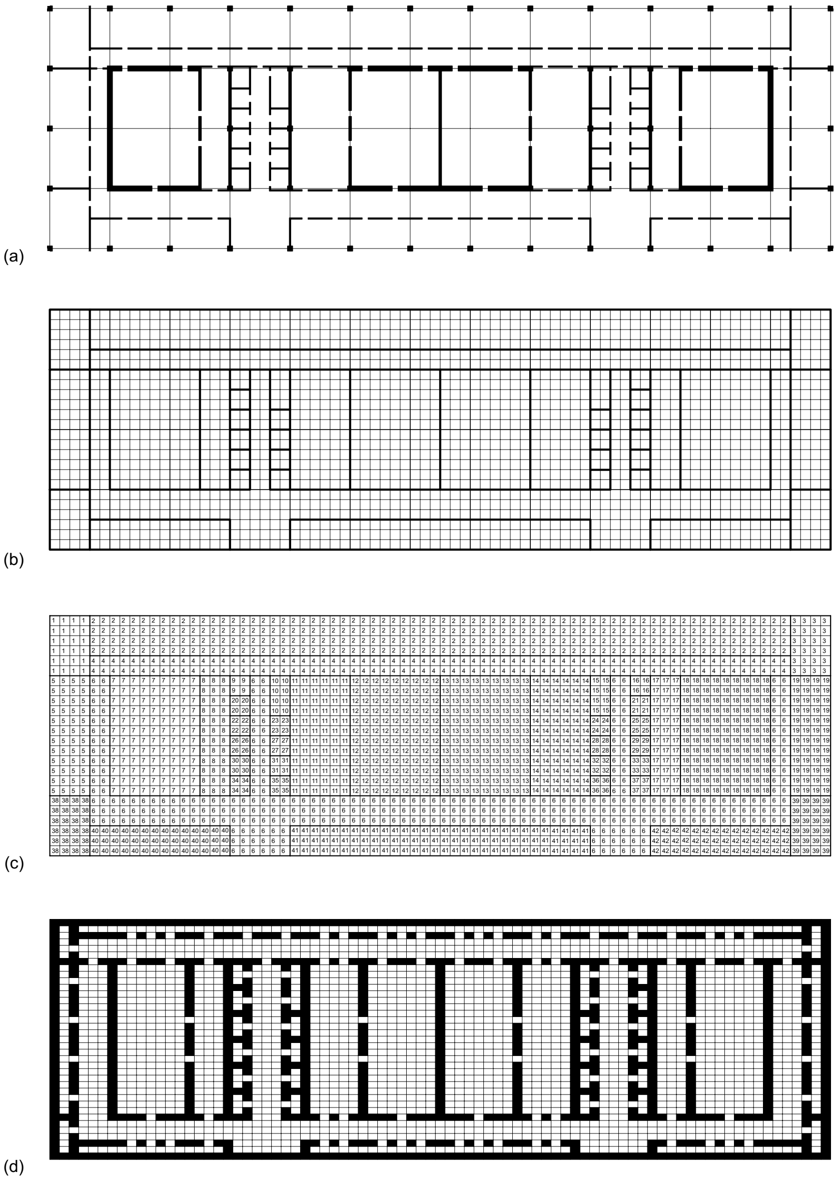
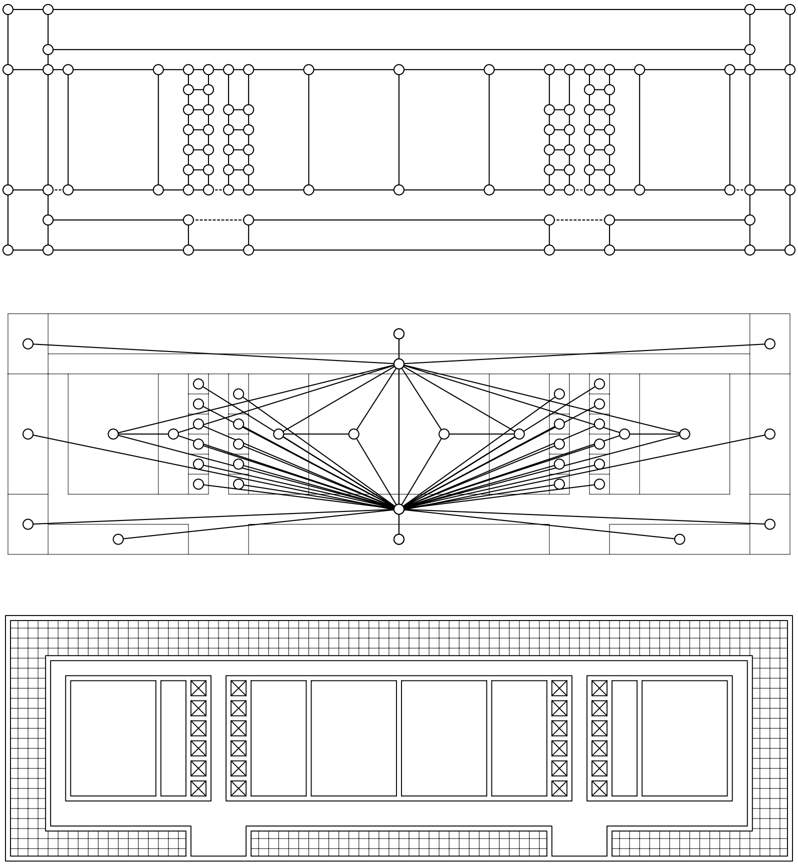


Fig. 3 A formal analysis of the typical courtroom plate of the Dirksen Courthouse: **a** schematic representation; **b** gridiron representation; **c** regular square grid representation; **d** dimensionless representation of solids and voids; **e** dimensionless representation of spaces; **f** polygon graph representation; **g** dual graph representation; and **h** composite figure-ground representation

1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3
1	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3
5	6	7	8	9	6	10	11	12	13	14	15	6	16	17	18	6	19
5	6	7	8	20	6	10	11	12	13	14	15	6	21	17	18	6	19
5	6	7	8	22	6	23	11	12	13	14	24	6	25	17	18	6	19
5	6	7	8	26	6	27	11	12	13	14	28	6	29	17	18	6	19
5	6	7	8	30	6	31	11	12	13	14	32	6	33	17	18	6	19
5	6	7	8	34	6	35	11	12	13	14	36	6	37	17	18	6	19
38	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	39
38	40	40	40	6	6	6	41	41	41	41	6	6	6	42	42	42	39

(e)



(f)

(g)

(h)

Fig. 3 (continued)

generative model because it simultaneously provides two complementary models—the model of architectural elements (solids) and the model of functional spaces (voids). For legibility, the vertical cores and the office spaces are denoted here with conventional circumscribed X-notations and 4′-8″ square grids respectively and the courtrooms and supporting spaces within the inner region are foregrounded as the primary figures.

The floor-to-floor height of the building is precisely 12′–0″ and it subdivides into 3′–0″ of slab and 9′–0″ of space: the 3′–0″ slab is the practical requirement for the fire safety and the 9′–0″ space is the design requirement requested by the client, the GSA (Architectural Design 1964). Interestingly, the total length of the 13 bays, equals 364 feet, and the total height of the 30 floors, equals to 360 feet, forms an impressive front façade that is nearly a square in proportion (Speyer and Koeper 1968) and completes the form of a pristine three-dimensional rectangular prism with proportions 4:13:13.

The Variations of the Dirksen Courthouse

The formal analysis of Dirksen Courthouse's courtroom plate, as documented in the drawings published upon the completion of the building (Architectural Record 1965), provides the initial set of lenses to start looking at the fascinating and enigmatic corpus of the 135 sketches produced in the office of Mies during the design process of the courthouse and documented in the Mies van der Rohe Archive (Mies van der Rohe et al. 1992). Among the eight representations used to model the published original plan and extract insights on the geometric composition of the courtroom plate and the ring in particular, the composite figure-ground representation is selected as the most useful model for the production of a new corpus because (a) it captures concisely the basic compositional armature of the design in terms of solids (columns, walls and panels) and voids (rooms and corridors) and (b) it provides a set of clearly defined spatial relations of the components that can be used in a straightforward way for the design of parametric shape rules in the form of a parametric shape grammar that can generate Mies' courtroom plate design variations as well as new possible ones.

The characterization of the 135 sketches in terms of the five spatial elements of the courtroom plate, namely, (a) courtrooms, (b) supporting spaces, (c) ring, (d) vertical cores and (e) offices, produces 36 distinctively significant Miesian courtroom plate design variations that are all scaled and redrawn under an identical set of conventions to further emphasize their similarities and differences. These variations are all distinguished in terms of overall dimensions, proportional configurations, number of courtrooms, rectangular or T-shape footprints, distribution of vertical cores, overall shape and so forth. Their proportional relations are significant: the complete corpus splits into seven types based on underlying structural grids, namely, the 4:9, 4:11, 4:12, 4:13, 4:14, 5:10 and 5:15 configurations. The regulating unit for all such configurations is the ubiquitous Miesian structural module measuring 28′–0″ × 28′–0″ and the overall dimensions of each variation follow these proportions in straightforward ways. For example, the 4:9 configuration consisting of four structural bays in the transverse direction and 9 structural bays in the longitudinal direction measures 112′×252′. The rest follow through with dimensions 112′×364′, 112′×308′, 112′×336′, 112′×364′, 112′×392′, 140′×280′ and 140′×420′ respectively. In addition to these proportional differences, these 36 selected sketches come from diverse states in the design process showcasing different kinds and degrees of detail each providing design features that are not necessarily repeated in the other sketches. Still, the clarity of inquiry and the economy of means illustrate a very precise inquiry on the possibilities of the schematic configuration and the overall arrangement of the courtroom plate and its correspondence with the ground floor plan. The set of 36 models forming the corpus of the work is given in Fig. 4.

The corpus of the 36 remodeled two-dimensional diagrammatic courtroom plate representations provides a significant first insight in the critical reflection of the compositional armature of the design. First, the use of bilateral symmetry is overwhelming and clearly shows the classical tendency of the architect to operate in a very formal framework. All courtroom plate design variations explicitly feature bilateral symmetry with respect to the central axis in the traverse direction and subtle asymmetry respect to the central axis in the longitudinal direction—celebrating the public front and affixing the restricted back of the courthouse. Second, the use of the ring is ubiquitous in all the variations. It resolves the complex relations between the five types of spaces and typically demarcates an inner region and an outer region of functional spaces across the courtroom plate. The courtrooms and supporting spaces are composed within the inner region and arrays of offices and public spaces are arranged along the outer ring. The inner region is further conditioned by three constraints: a) a valid composition must maintain the bilateral symmetry at all time, b) it must have at least one bridging corridor in the transverse direction and c) it must have a reasonable ratio between the areas of courtrooms and supporting spaces. More precise features can be extracted too: the corpus suggests that the ratio between the areas shall be within the range from 1:0.4 to 1:1.1 and the average ratio is 1:0.8. Third, the overall footprint of the plate is either rectangular or T-shape with a predominance of the first type. While these variations demonstrate a constructive inquiry of the courtroom plate type, it is unclear though whether more formal types could be conjectured, whether more proportional types could be postulated based on other multiples of the structural grid, and more importantly, how these variations can affect the sectional properties of the complete building. Finally, the corpus defines finite sets of possible courtrooms and supporting spaces in terms of their width and length. These sets of variations are parametrically defined: n as a multiplier of the Miesian spatial module, all variations are commensurable following the underlying grid. There are 12 variations of courtroom and 36 variations of supporting space. The four possible dimensions in width and three possible dimensions in length allow 12 courtroom variations: $width_c = \{8n, 9n, 10n, 12n\}$ and $length_c = \{12n, 16n, 18n\}$, the 12 variations are $8n{:}12n$ (2:3), $8n{:}16n$ (1:2), $8n{:}18n$ (4:9), $9n{:}12n$ (3:4), $9n{:}16n$ (9:16), $9n{:}18n$ (1:2), $10n{:}12n$ (5:6), $10n{:}16n$ (5:8), $10n{:}18n$ (5:9), $12n{:}12n$ (1:1), $12n{:}16n$ (3:4) and $12n{:}18n$ (2:3). Similarly, the 12 possible dimensions in width and three possible dimensions in length allow 36 supporting space variations: $width_s = \{2n, 3n, 4n, \ldots, 18n\}$ and $length_s = \{12n, 16n, 18n\}$.

Fig. 4 The set of 36 two-dimensional diagrammatic representations of the postulated Miesian courtroom plate design variations

The Grammar of the Dirksen Courthouse

The corpus of the 36 Miesian courtroom plate design variations pictorially presented in the forms of the remodeled two-dimensional diagrammatic representations is undertaken here to comprise Mies van der Rohe's courthouse design language. This architectural language is captured by a generative description in the form of a three-dimensional parametric shape grammar (Stiny 2006). Information about the sectional properties of the rules and the grammar at large is supplemented in an identical way for all design variations combining lessons learned from the visual inspection of the published sections of the Dirksen Courthouse (Architectural Record 1965). The rules of the parametric shape grammar are given in four types of representation: (a) a three-dimensional representation (axonometric projection) to enable the spatial coordination of plan and section within a singular representation; (b) a two-dimensional representation (orthographic projection) to emphasize the aspects of the plan organization of the courtroom plate and mostly to help disambiguate aspects of legibility and visual inspection (Economou and Grasl 2018); (c) a graph representation to capture functional and adjacency relations between the different spatial elements of the rules; and (d) a C# script encoded in the three-dimensional parametric shape grammar interpreter, GRAPE, to implement the rules in a software environment (Grasl and Economou 2013).

The rules are designed in these four types of representation for different purposes: the three-dimensional and two-dimensional representations are used to encode the spatial aspects of the formal analysis into a set of spatial rules that can generate actual and hypothetical designs; the graph representation is used to transfer the lessons learned from the three-dimensional and two-dimensional rules into a mathematical model that can be computed in a machine; and the script is used to encode the graph representation in the executable format of the interpreter. The interplay of all these representations is important for the design of the grammar itself: insights from the three-dimensional representations were retroactively introduced in the two-dimensional representations and vice versa and both informing the graph representations and thus the script. For legibility, only the two-dimensional representations of the grammar are given here to emphasize the visual inspection and reflection of the proposed rules by the reader while the productions of the grammar—the results of the machine-executed computation within the GRAPE-enabled three-dimensional software environment—are given in axonometric projections of the three-dimensional outputs. The correspondence of the four representations are given visually for a single rule in Fig. 5 and the conventions to facilitate the correspondence between them are briefly discussed below.

For the parametrization, a set of four global variables is declared to incorporate the proportional system and modularity of the Miesian design language (Fig. 5a). The variable *n* represents the smallest commensurable unit, the Miesian spatial module measuring 4′-8″ or 56″; the variable *m* represents the Miesian structural module that is comprised of six spatial modules and measures 28′–0″ or 336″ corresponding to the steel frame structural system; the variable *h* represents the floor-to-floor sectional module and measures 12′–0″ or 144″; and the variable *k* represents the nominal thickness of poché comprised of tectonic elements including columns, beams, walls and slabs. Then, parameters with respect to the global variables are employed in three different ways to control the rules. First, constants are defined to provide an overall compositional structure for both recognitions and generations by specifying constant shapes; for example, the parameter *e* on the left-hand side constraints the rules to operate with respect to the pairs of stacked circulation corridors each measuring *k* (12′) in its height. Second, range parameters with specific increments are defined to enable parametric recognitions of multiple shapes; for example, the parameter *s* on the left-hand side parameterizes the rule in a way that the rule is applicable to any pair of courtrooms where the horizontal distance between the two courtrooms is within the range from 2*n* to 58*n*. Third, set parameters are defined for the left-hand side to enable controlled recognitions of shapes and for the right-hand side to generate parametrically defined shapes. For example, on the left-hand side, the parameters *c* and *d* restrict the rules to only recognize the shapes that measure 2–3*m* in their lengths. Similarly, the parameters *a* and *b* restrict the rules to only recognize the shapes that measure to the specifications in their widths. On the right-hand side, the parameter *f* enables a parametric generation of a pair of supporting spaces each measuring 2*n*, 4*n*, 5*n*, 6*n*, 8*n*, 9*n*, 10*n*, 12*n* or 14*n*.

Labels are presented along with the two-dimensional representations of the grammar and used in two different ways (Fig. 5b). First, the labels O, X, X′, A and A′ are associated with the regulating axes and employed to guide the generation of courtroom plate compositions specifying the front and back, left and right and the boundary of the ring throughout the generations. Second, the labels C, S, E, B, R, R′, F, F′, T, T′, L, Y and Z are associated with rectilinear shapes that denote rooms and corridors and are employed to provide functional descriptions of the corresponding spaces. For example, a label C specifies a courtroom; a label S specifies a supporting space; a label E specifies a short side of the ring corridor; a label B specifies a bridging corridor; labels R and R′ as a pair specify a long side of the ring corridor; labels F and F′ as a pair specify an array of office spaces along the periphery; and labels T and T′ as a pair specify a skybox or public waiting area extending from the ring corridor. Also, conventional circumscribed X-notations are employed to specify elevator cores. Finally, a numerical convention is employed to structure the four sectional volumes of the courthouse: the double-height lobby at the ground floor, a series of office floors upon the ground floor, a series of courtroom floors upon the office floors and the mechanical floor on the top are in 2:3:4:1 ratio in their heights.

The Dirksen grammar consists of a total of 78 three-dimensional parametric shape rules organized in seven stages that correspond to an inside out design process starting from the core of the functional typology of the courthouse, the courtrooms and their associated spaces, to the deployment of these modules to capture the core of the courtroom plate, and to the generation of the complete schematics including all courtrooms and supporting spaces, corridors, offices and elevators. The seven stages are: (1) Initialization; (2) Courtrooms; (3) Ring; (4) Partition; (5) Boundary; (6) Section; and (7) Termination. A brief description of each stage and the complete set of shape rules presented in two-dimensional representations follow below.

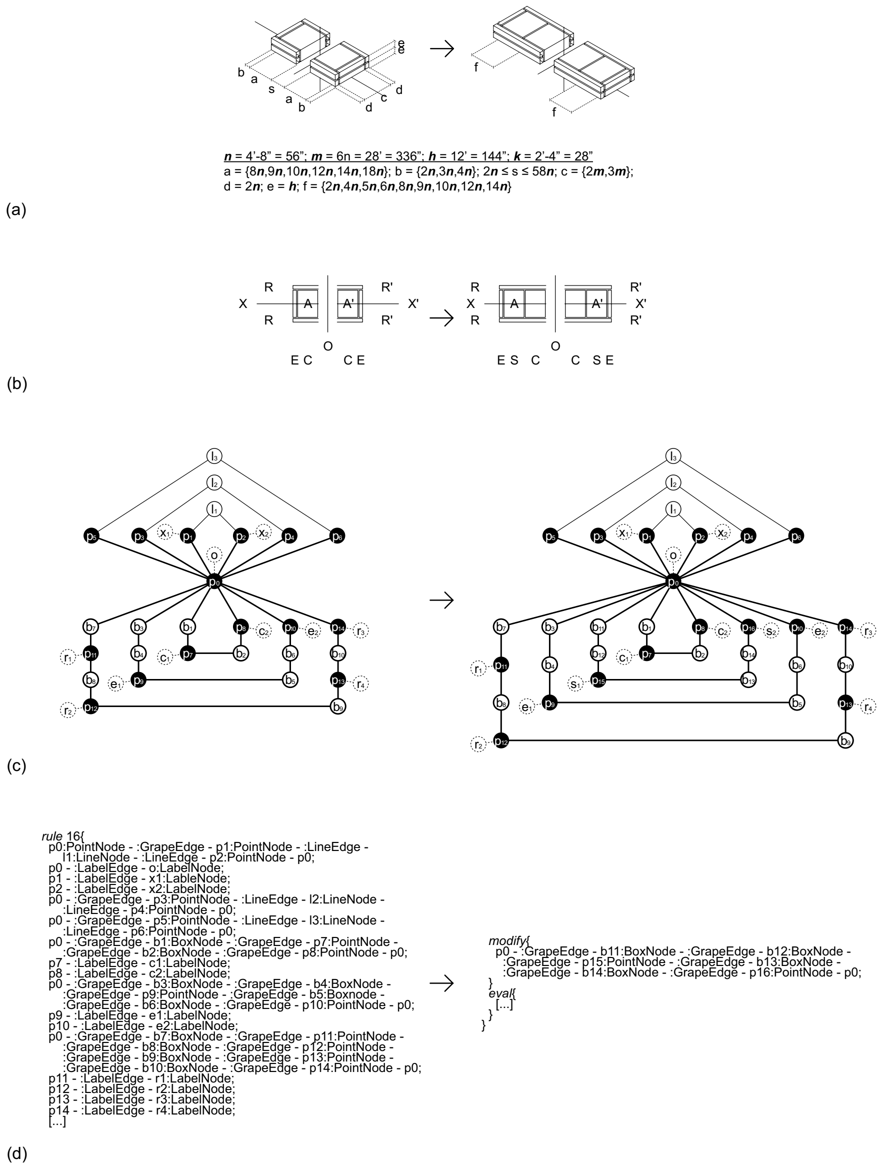


Fig. 5 Rule 16 presented in four types of representation: **a** an axonometric projection of the rule; **b** an orthographic projection of the rule; **c** a graph representation of the rule; **d** a script encoding the graph representation of the rule

Stage 1: Initialization

The first stage consists of six rules and generates the initial shapes for the grammar (Fig. 6). Rule 1 initializes the generation of the design by establishing regulating axes of symmetry defining the overall shape of courtroom plate—either 4:9, 4:11,

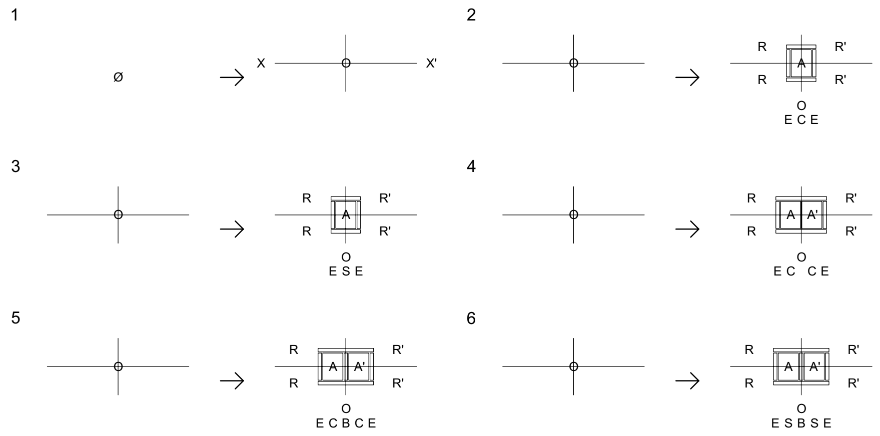


Fig. 6 Stage 1: Initialization (Rules 1–6)

4:12, 4:13, 4:14, 5:10 or 5:15. Rules 2–6 generate an initial shape in five possible ways: Rule 2 generates a central courtroom and the corresponding ring corridor; Rule 3 generates a central supporting space and the corresponding ring corridor; Rule 4 generates a central pair of courtrooms and the corresponding ring corridor; Rule 5 generates a central pair of courtrooms with a bridging corridor in-between and the corresponding ring corridor; and Rule 6 generates a central pair of supporting spaces with a bridging corridor in-between and the corresponding ring corridor. The selection of the initial rule fixes the compositional scheme of this inner region of the courtroom plate and the labels A and A′ are symmetrically positioned to ensure that the application of the subsequent rules will keep the overall bilateral symmetry of the design. For example, generating a single central courtroom (Rule 2) guarantees that the final composition contains an odd number of courtrooms and conversely generating a central pair of courtrooms (Rule 4 or 5) will result an even number of courtrooms.

Stage 2: Courtrooms

The second stage consists of 14 rules and continues the development of the inner region composition by adding courtrooms and supporting spaces in both sides of the horizontal axis of the courtroom plate (Fig. 7). Rule 7 adds a pair of courtrooms adjacent to a central courtroom; Rule 8 adds a pair of courtrooms with a pair of bridging corridors adjacent to a central courtroom; Rule 9 adds a pair of supporting spaces adjacent to a central courtroom; Rule 10 adds a pair of supporting spaces with a pair of bridging corridors adjacent to a central courtroom; Rule 11 adds a pair of courtrooms to a central supporting space; Rule 12 adds a pair of courtrooms with a pair of bridging corridors adjacent to a central supporting space; Rule 13 adds a pair of supporting spaces with a pair of bridging corridors adjacent to a central supporting space. These seven rules recognize a central courtroom or supporting space generated by Rules 2 or 3 in the Stage 1 and add either a pair of courtrooms or a pair supporting spaces with or without a pair of bridging corridors. Rule 14 adds a pair of courtrooms adjacent to a central pair of courtrooms; Rule 15 adds a pair of courtrooms with a bridging corridors adjacent to a central pair of courtrooms; Rule 16 adds a pair of supporting spaces to a central pair of courtrooms; Rule 17 adds a pair of supporting spaces with a pair of bridging corridors adjacent to a central pair of courtrooms; Rule 18 adds a pair of courtrooms adjacent to a central pair of supporting spaces; Rule 19 adds a pair of courtrooms with a pair of bridging corridors adjacent to a central pair of supporting spaces; and Rule 20 adds a pair of supporting spaces with a pair of bridging corridors adjacent to a central pair of supporting spaces. Rules 14-20 recognize a symmetrical pair of courtrooms

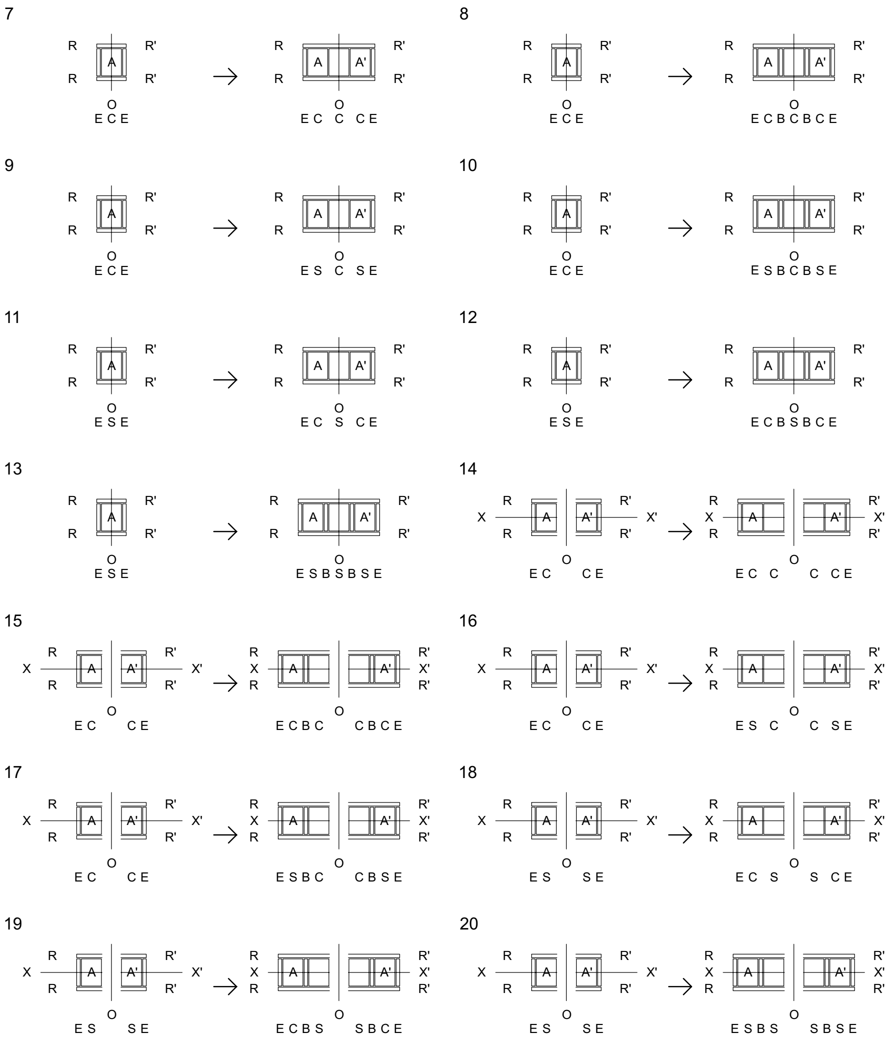


Fig. 7 Stage 2: Courtrooms (Rules 7–20)

or supporting spaces and add a pair of courtrooms or supporting spaces with or without a pair of bridging corridors. All 14 rules in this stage also scale the ring corridor according to the additions of spaces and translate the labels A and A’ to mark the spaces positioned at the most ends of both sides guiding the continuation of inside-out growth of the composition.

Stage 3: Ring

The third stage consists of 16 rules and generates variations of the ring corridor defining public and restricted sides of the courtroom plate (Fig. 8). Rule 21 finalizes the composition of the inner region by removing the labels A and A′ and adding an array of office spaces along the periphery. Rule 22 removes the two short sides of the ring corridor on each end and expand the adjacent office spaces. This rule is for the generation of the design 1-03 in the corpus. Rule 23 replaces the two short sides of the ring corridor with office spaces by changing the labels E to labels F and slightly enlarging the spaces. This rule is for the generation of the design 4-02 in the corpus. Rule 24 expands the office spaces at the corners and compresses the longitudinal corridors. This rule is for the generation of the design 1-03 uniquely featuring corridor-less configuration with expanded lobbies at the front and back. The following six rules, Rules 25-30, transform the longitudinal parts of the ring corridor in most cases to define the public front of the courtroom plate by expanding one or both corridors. Rule 25 expands both longitudinal corridors by 1*n* and scale the adjacent office spaces accordingly; Rule 26 expands one longitudinal corridor by 1*n* and scale the adjacent office spaces accordingly; Rule 27 expands one longitudinal corridor by 4*n* and removes the adjacent office space. Rule 28 expands a central portion of one longitudinal corridor by 4*n* and removes the corresponding central portion of the office space; Rules 29 and 30 are symmetrical variations of Rules 27 and 28. The following three rules, Rules 31–33, expand a pair of bridging corridors in their widths preparing for the vertical core compositions of certain designs in the corpus—including the designs 2-01, 5-01, 6-01 and 7-01. Rule 31 expands a pair of bridging corridors each in-between pairs of supporting spaces by 3*n*; Rule 32 expands a pair of bridging corridors each in-between a pair of supporting spaces by 2*n* doubling the widths; and Rule 33 expands a pair of bridging corridors adjacent to a central supporting space by 1*n*. The following two rules, Rules 34 and 35, generate skyboxes or public waiting areas. Rule 34 generates a pair of skyboxes adjacent to the public corridor, the front corridor that is a part of the ring corridor, aligned with a pair of bridging corridors creating linear spatial expansions for the public along the bridging corridor in direction towards the skyboxes and beyond; similarly, Rule 35 generates a pair of skyboxes adjacent to the public corridor aligned with two pairs of courtrooms at the ends of the courtroom plate composition. Finally, Rule 36 compresses the back corridor, for the restricted circulation, and expands the adjacent office space accordingly. This rule is for the generation of the design 4-13 in the corpus.

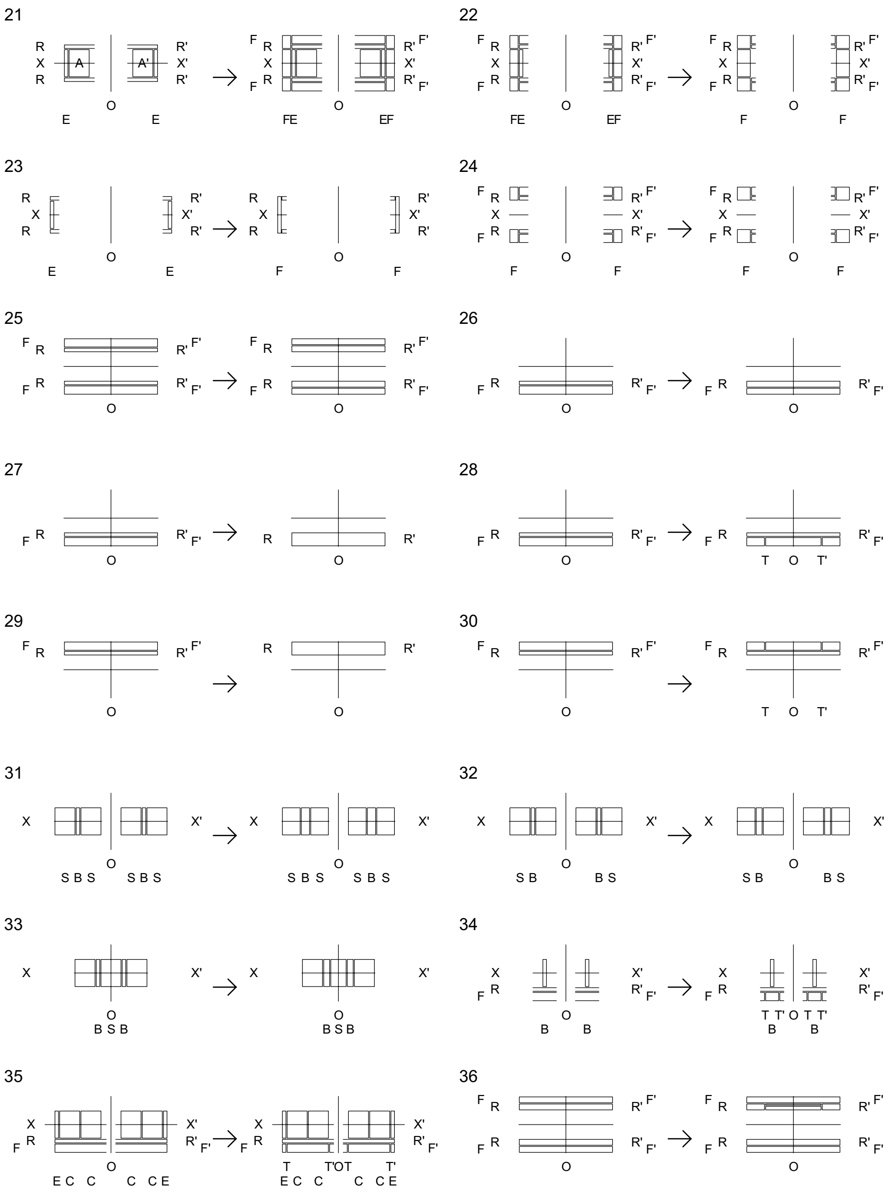


Fig. 8 Stage 3: Ring (Rules 21–36)

Stage 4: Partition

The fourth stage consists of 12 rules and selectively transforms supporting spaces, corridors and office spaces preparing the design for the further transformations of the overall schematic structure of the courtroom plate and its vertical cores (Fig. 9).

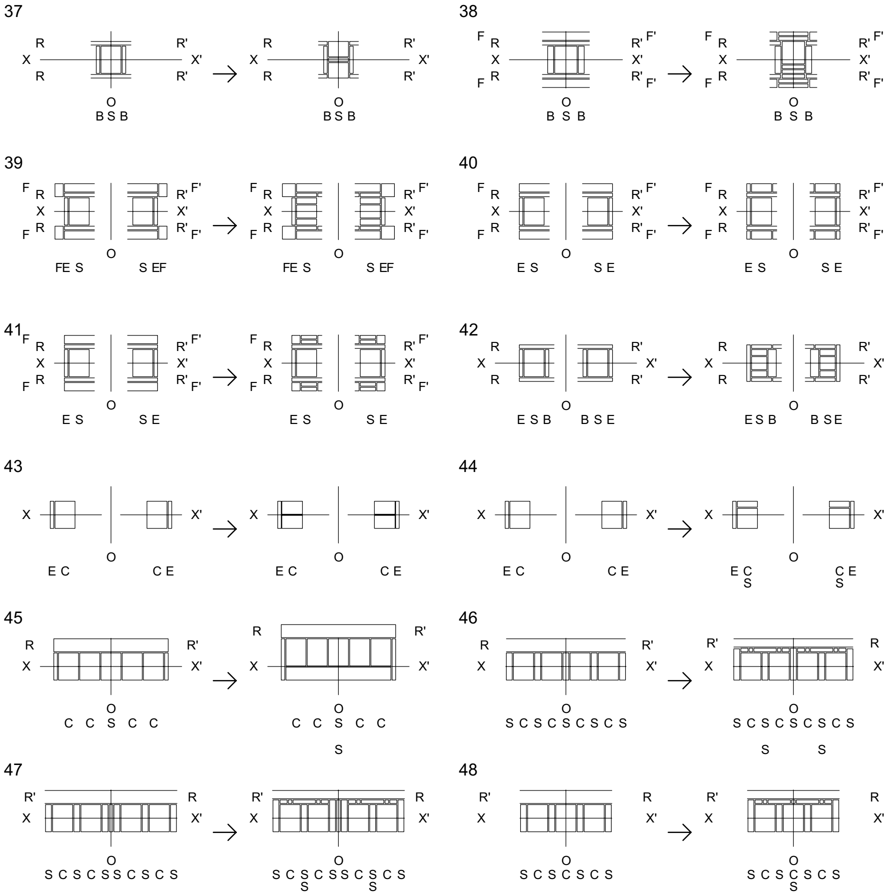


Fig. 9 Stage 4: Partition (Rules 37–48)

Rules 37 and 38 transform a central supporting space and related office spaces and add horizontal bridging corridors to prepare for the generations of rotated arrays of vertical cores in the next stage (Rules 59 and 60). These rules are for the generations of the designs 6-01 and 1-04 in the corpus. Similarly, the following four rules, Rules 39–42, transform and add spaces to prepare for the generations of the rotated arrays of vertical cores—more specifically, for the designs 1-08, 4-13, 3-02 and 4-12 in the corpus respectively. Rule 43 divides a pair of courtrooms (each measuring 3*m* in its width) resulting four rotated courtrooms. This rule is for the generation of the design 6-01 in the corpus. Rule 44 scales a pair of courtrooms and adds a pair of supporting spaces adjacent to the courtrooms, on the restricted side of the courtroom plate. This rule is used for the generation of the design 5-01 in the corpus. Finally, the following four rules, Rules 45–48, transform the inner region as a whole to generate the unique treatments of courtroom fronts found in the corpus, for the designs 5-01, 5-06, 5-04 and 5-07 respectively.

Stage 5: Boundary

The fifth stage consists of 22 rules and generates vertical cores and arrays of elevators establishing the sectional relationship of the courtroom plate with the rest of the courthouse (Fig. 10). The first ten rules in this stage, Rules 49–58, generate vertical cores within the inner region of the courtroom plate based on the arrangement of supporting spaces and bridging corridors generated in the Stages 1 and 2. Rule 49 takes parts of a pair of central supporting spaces with a central bridging corridor in-between and generates two sets of vertical cores adjacent to the bridging corridor. This rule is used for the generations of the designs 1-02, 1-03, 1-05 and 1-06 in the corpus. Rule 50 is a variation of Rule 49. This rule takes a central pair of supporting spaces that measure $2n$ in their widths exclusively and replace them with vertical cores and is for the generation of the design 4-04 in the corpus. Rule 51 recognizes a central courtroom and a pair of supporting spaces that measure $2n$ in their widths, with a pair of bridging corridors in-between, and replaces the pair of supporting spaces with two sets of vertical cores. Rule 52 takes parts of two pairs of supporting spaces with a pair of bridging corridors in-between the supporting spaces in each pair and a central bridging corridor in-between the pairs and generates four sets of vertical cores all adjacent to the bridging corridors. This rule is used for the generation of the design 4-06 in the corpus. Similar to Rule 51, Rule 53 takes parts of a pair of supporting spaces with a pair of bridging corridors and a central courtroom and generate two sets of vertical cores. This rule is used for the generation of the design 2-01 in the corpus. Rule 54 takes parts of a pair of supporting spaces with a pair of bridging corridors and a pair of courtrooms in-between and generates two sets of vertical cores adjacent to the bridging corridors. This rule is used for the generations of the designs 3-01 and 4-01 in the corpus. Similarly, Rule 55 takes parts of a pair of supporting spaces with a pair of corridors and another pair of supporting spaces in-between and generates two sets of vertical cores adjacent to the bridging corridors. Rule 56 takes parts of two pairs of supporting spaces with a bridging corridor in-between the supporting spaces in each pair and generates four sets of vertical cores. This rule is most often applied to generate the designs in the corpus. Rule 57 takes parts of a pair of supporting spaces with a pair of bridging corridors and another pair of supporting spaces that measure $2n$ in their width and generates four sets of vertical cores all adjacent to the bridging corridors. This rule is used for the generation of the designs 4-07 in the corpus. Rule 58 recognizes two pairs of supporting spaces all measuring $2n$ in their widths with a bridging corridor in-between them for each pair and replaces them with four sets of vertical cores. The following 8 rules, Rules 59–66, are used for the generations of the unique designs in the corpus—for the designs 1-04, 6-01, 1-08, 4-12, 3-02, 4-13, 1-07 and 4-10 respectively. Finally, the last four rules, Rules 67-70, generate vertical cores for the designs featuring T-shape courtroom plates including the designs 1-01, 1-09, 4-08, 4-09, 4-10, 4-11, 5-01, 5-04, 5-05, 5-06, 5-07 and 5-08 in the corpus.

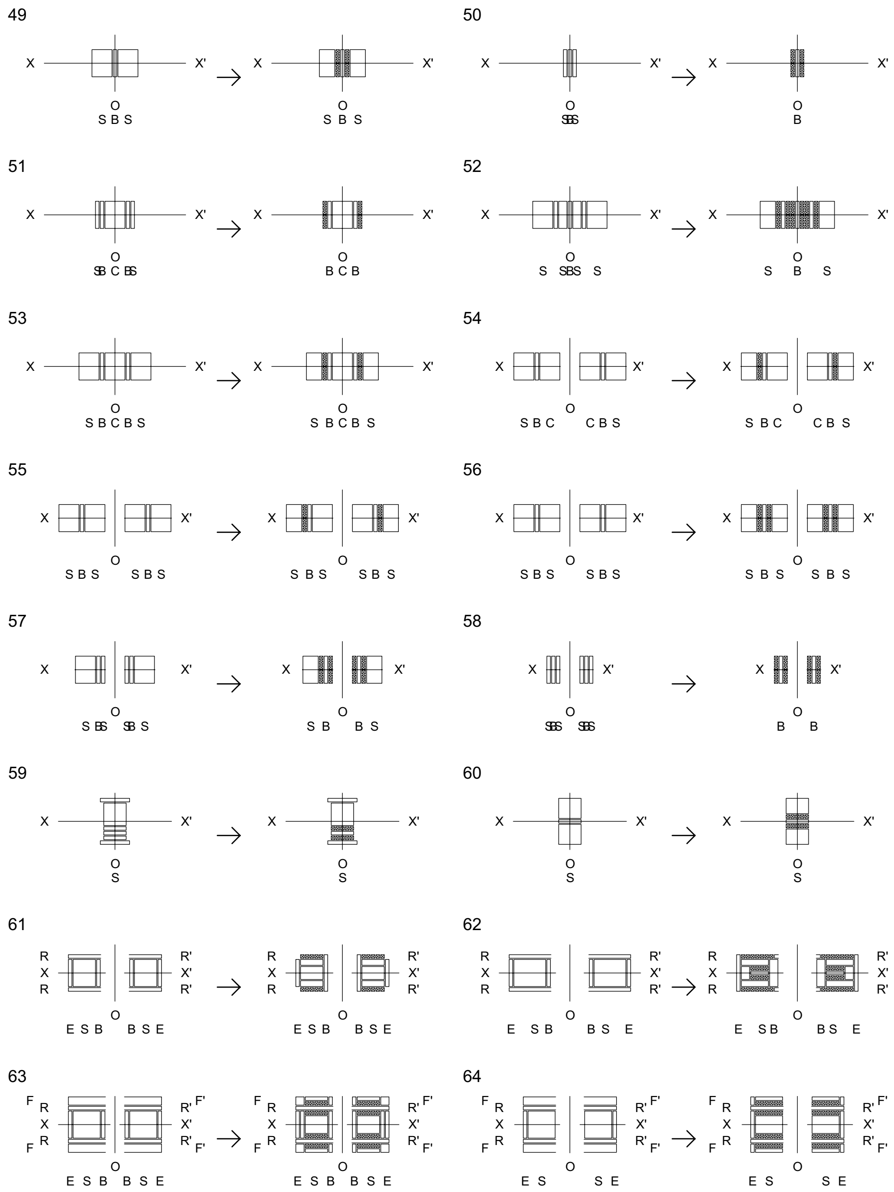


Fig. 10 Stage 5: Boundary (Rules 49–70)

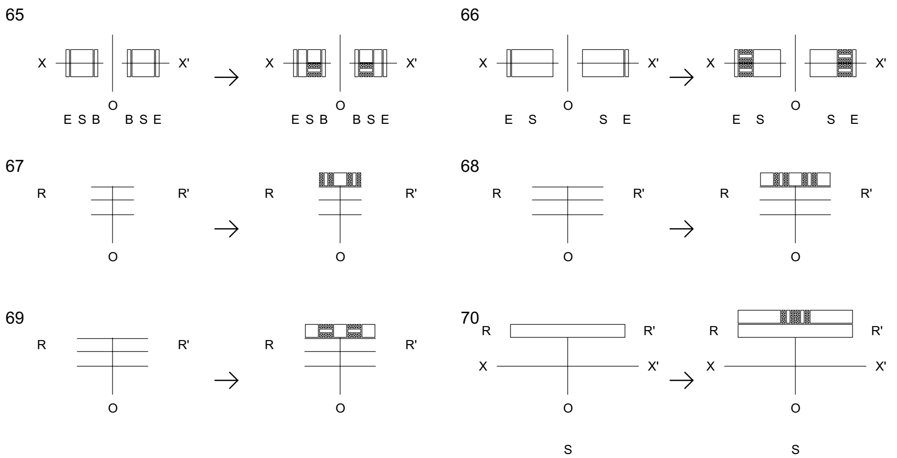


Fig. 10 (continued)

Stage 6: Section

The sixth stage consists of 7 rules completing the body of the courthouse designs (Fig. 11). Rule 71 recognizes a complete courtroom plate consisting of courtrooms, supporting spaces, corridors and office spaces, and measuring $2h$ in its height and vertically translates the entire plate by $3h$. Rule 72 scales a vertical core vertically with an origin at the ground plane of the design by its height plus $3h$. Rule 73

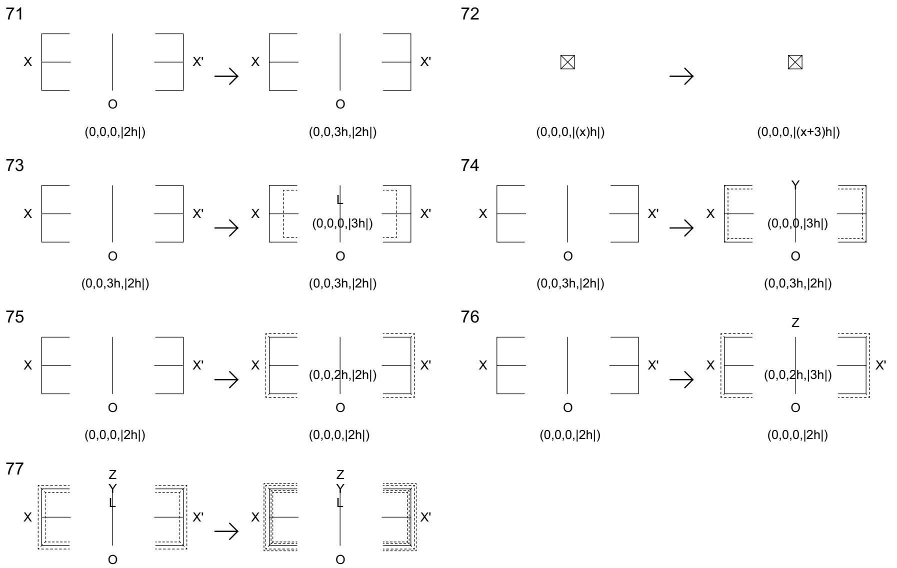


Fig. 11 Stage 6: Section (Rules 71–77)

generates a public lobby proportional and in relation to the courtroom plate that is vertically translated from the ground plane by $3h$. Rule 74 generates three floors of office floors proportional and in relation to the courtroom plate that is vertically translated from the ground floor by $3h$. Rule 75 generates a copy of a courtroom plate and vertically translates the copied courtroom plate by $2n$ to bring it on top of the original courtroom plate. Rule 76 generates three floors ($3h$) of mechanical floors on top of the upmost courtroom plate. Finally, Rule 77 generates a building envelope encompassing a complete courthouse design that consists of courtroom plates, public lobby, office floors and mechanical floors. In addition to Fig. 11, sample applications of these sectional rules are further illustrated within a sample derivation (Fig. 13) presented in axonometric projections.

Stage 7: Termination

The final stage consists of a single rule, Rule 78 (Fig. 12). The rule eliminates all labels, namely, O, X, X′, C, S, E, B, R, R′, F, F′, T, T′, L, Y and Z, and terminates the generative process.

Software Implementation

A significant characteristic differentiating the design of the Dirksen grammar from the majority of the shape grammars in the literature is that the rules in the grammar are implemented within a parametric shape grammar interpreter. The specific shape grammar interpreter selected for the authoring and testing of the rules is the GRAPE and more specifically its version for Rhinoceros 3D, GRAPE for Rhino. In this environment, shape rules are translated into graph representations which are then encoded into a graph grammar definition using the GRAPE library. For this particular iteration of implementation, the rectangular prism is employed as the primary primitive shape to focus on the three-dimensional aspects of the investigation.

A sample derivation of a Miesian courthouse design is illustrated in Fig. 13 as a direct three-dimensional output of the implementation. This sample derivation illustrates specific aspects of the generation process of a Miesian courthouse based on the corpus of the courtroom plate design variations discussed above. The complete derivation requires 42 steps but here only 12 steps are illustrated to capture significant decision-making moments in the design process. The 12 generative steps are given in a boustrophedon manner, that is, a bidirectional production unfolded from left-to-right and right-to-left in alternate lines generating a series that starts from the top-left and ends at the bottom left. The applications of rules are explicitly

78

⟨sØ, {(0,0): (O,X,X',C,S,E,B,R,R',F,F',T,T',L,Y,Z)}⟩ ⟶ ⟨sØ, Ø⟩

Fig. 12 Stage 7: Termination (Rule 78)

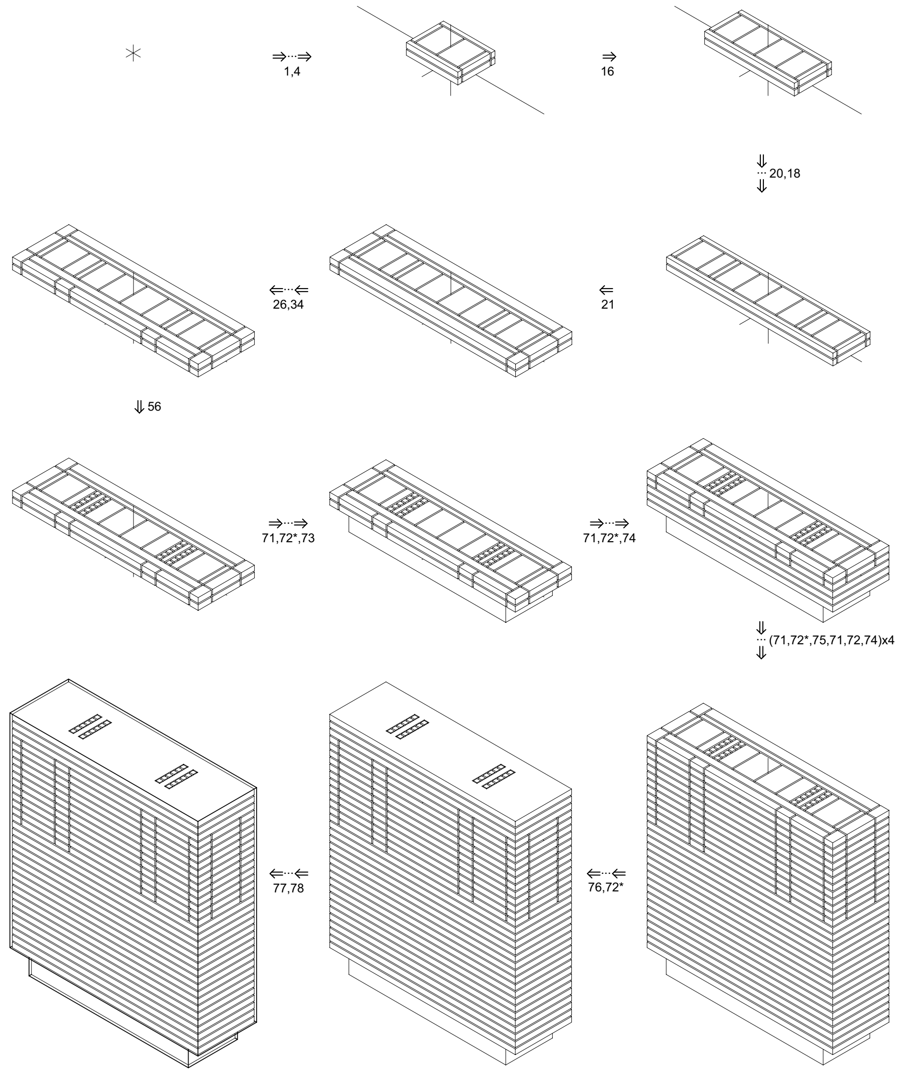


Fig. 13 A sample derivation of a Miesian courthouse design from the software implementation of the Dirksen grammar in GRAPE (Grasl and Economou 2013): the actual design of the Dirksen Courthouse

given in each step; and when a rule is uniformly applied to all the applicable shapes recognized within a given design instance, it is notated with an asterisk (*).

The origin and the orientation of the generation in three-dimensional space is specified in the first step; in the second step, overall shape and dimensions of the courtroom plate are specified and the first pair of courtrooms with corresponding ring corridors are generated (Rules 1 and 4); in the third step, a pair of supporting spaces associated with the first pair of courtrooms is generated and the ring corridors are transformed accordingly (Rule 16); in the fourth step, a pair of bridging corridors within the ring corridors and a pair of supporting spaces are generated for potential generation of vertical cores later in the process and also a new pair of courtrooms are generated adjacent to the new supporting spaces (Rules 20 and 18); in the fifth step, two arrays of stacked office spaces along the periphery are generated completing the courtroom plate generation (Rule 21). In the sixth step, the longitudinal corridor on the front, a part of the ring, is expanded to have more generous width as a public space and a pair of stacked skyboxes or public waiting areas is generated (Rules 26 and 34). In the seventh step, two symmetrical pairs of vertical cores are generated specifying the relationship between the courtroom plate and the public lobby at the ground floor (Rule 56); in the eighth step, the complete courtroom plate is translated vertically upwards, the vertical cores are scaled accordingly and a double-height public lobby is generated on the ground level (Rules 71, 72* and 73); similarly, in the ninth step, the courtroom plate is translated, vertical cores are scaled and three office floors are generated in-between the lobby and the courtroom plate completing the minimal courthouse configuration (Rules 71, 72* and 74). In the tenth step, the courthouse configuration sectionally grows to satisfy the requirement of having 20 courtrooms by multiplying the courtroom plate and office floors in 1:3 ratio [(Rules 71, 72*, 75, 71, 72 and 74) $\times$ 4]; in the eleventh step, three mechanical penthouse floors are generated and the vertical cores are scaled to support these floors (Rules 76 and 72*); finally, a building envelope encompassing the complete courthouse design from the previous step is generated and all labels are removed to terminate the generative process (Rules 77 and 78).

A set of six three-dimensional courthouse models produced by the Dirksen grammar implemented in GRAPE are shown in Fig. 14. All models feature a core of 24 courtrooms in various configurations per floor: the model in Fig. 14a features 4 courtrooms per floor in a 1-2-1 arrangement and 6 double-height courtroom plates; the model in Fig. 14b features 3 courtrooms per floor in a 1-1-1 arrangement and 8 double-height courtroom plates; the model in Fig. 14c features 2 courtrooms per floor in a 1-1 arrangement and 9 double-height courtroom plates; the models in Fig. 14d–f feature corresponding configurations of courtrooms per floor but in different spatial arrangements. Interestingly, the first model (a) is a representation of the actual design of the Dirksen Courthouse; the two models (b) and (c) are representations of designs found in the documentation of the design process of Mies' office and depicted in the corpus (Fig. 4); and the last three models (d), (e) and (f) are representations of hypothetical designs possible within Mies' language captured by the grammar. All six models are derived by interactive applications of the rules of the Dirksen grammar, automatically produced using the GRAPE for Rhino, and presented herein sectional axonometric projections manually prepared for the illustrative purpose.

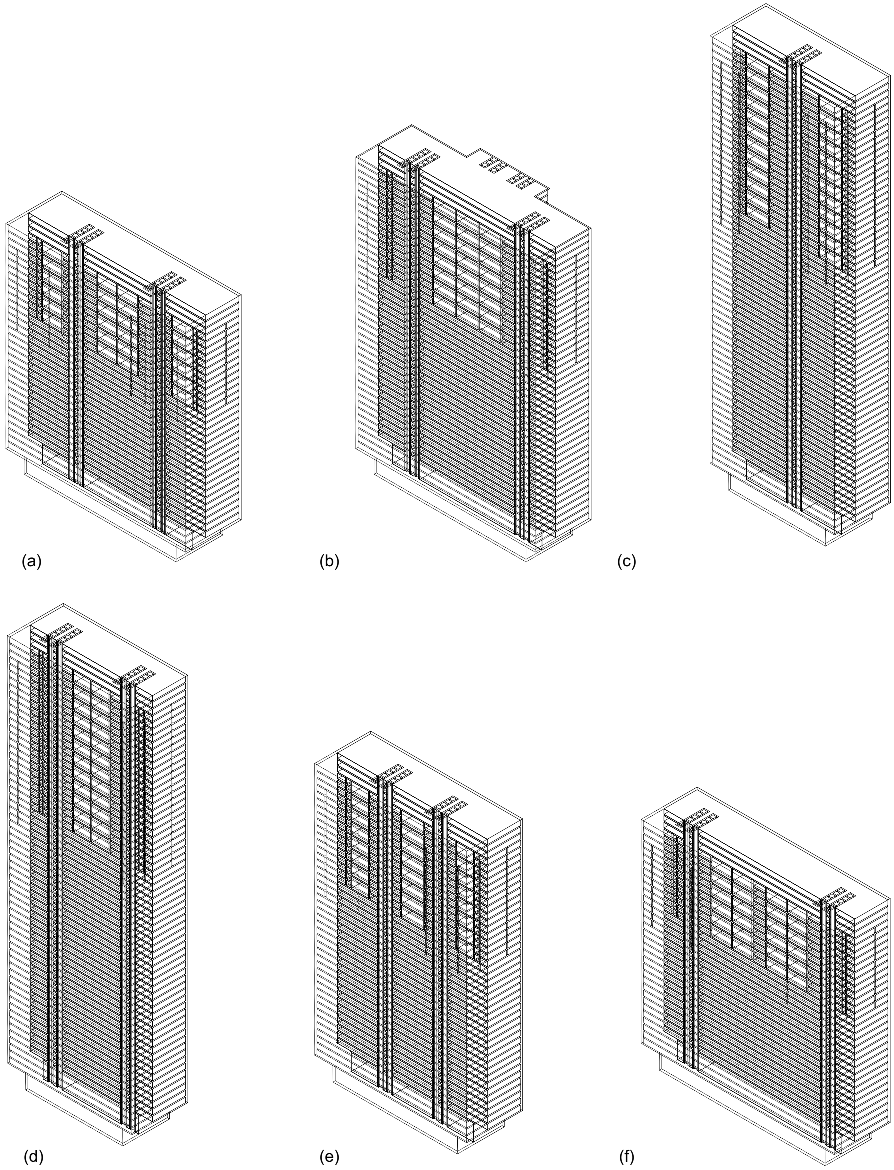


Fig. 14 Sectional models of six Miesian courthouse designs all satisfying the requirement of having 24 courtrooms and appropriate volume of public, office and supporting spaces: **a** the actual design of the Dirksen Courthouse; **b** the design variation 4-09 in the corpus; **c** the design variation 1-05 in the corpus; **d** a hypothetical design with two courtrooms per courtroom plate; **e** a hypothetical design with three courtrooms per courtroom plate; and **f** a hypothetical design with four courtrooms per courtroom plate

Discussion

The work presented here discussed the formal description of a pivotal building in the history of twentieth century architecture, Mies Van der Rohe's Everett McKinley Dirksen United States Courthouse, in the form of a parametric shape grammar. A significant element of the formal grounding of the design was the incorporation and redescription of the process drawings of the architectural office of Mies. These drawings, precisely because of their incompleteness and various levels of detail, provide an incredible opportunity to appreciate Mies' language and formal clarity in his architecture pervading all aspects of work in his office. It could not be otherwise, Mies was always an adamant proponent of principles and his work on the courthouse could not be different—"Architecture is a language, and I think you have to have a grammar in order to have a language. If you are good at that, you speak a wonderful prose; if you are really good, you can be a poet" (Mies van der Rohe 2007). While most of the beauty of Mies' work lies in detail, it is clear that this love for clarity and precision pervades his complete output, for every building type at any scale. The work remained at the scale of the abstract morphology selecting a particular planar representation to emphasize particular aspects of the courtroom plate. This was certainly a deliberate decision because the focus of this work was to understand Mies' usage of a particular architectural element, the ring, in his resolution of the morphology of courthouse design.

On a very different front, the Dirksen grammar is so far the most ambitious project in GRAPE taking on the complexities of writing new rules from scratch to specify a given corpus, parameterizing them to be able to fully capture specific proportional ideas, modeling all the rules in three-dimensions in a uniform way and implementing all directly in a CAD system. Clearly, these ambitions do not come without challenges. All rules are encoded directly in the scripting environment, an interface that is quite distinct from the visual one in the web version of the interpreter. Still, the current state of the work is promising in that it manages to produce models that can be exported and used in a variety of other applications. Interestingly, the majority of the rules in the grammar follow the schema rule $x + R(x) \rightarrow (x + y) + R(x + y)$—a similar schema rule to the one used in the Palladian grammar (Stiny and Mitchell 1978)—capturing the Miesian rules under the bilateral symmetry along the short axis of the courthouse. Moreover, the Dirksen grammar provides a three-dimensional analog for the Palladian one by modeling the in-between spaces of the building and having the walls and columns emerge as poché in a specific state of the production.

But more than both fronts discussed above, underlying motivation for the work has been the systematic exploration of the legacy of Mies' vision of courthouse design to the broader body of work on US contemporary courthouses (Courtsweb 2015). While courthouse design in the US is constituted by various aspects including economic, political, environmental and aesthetic, configuring a spatial organization that satisfies the functional requirement is essential of them all. Courthouse as a building type is highly complex addressing widely different functions pointing to wildly diverse ambitions and constraints. It is composed of courtrooms, judge's chambers, vast office spaces, a small jail, libraries, art galleries and a great public interface inscribed in transparent public lobbies and corridors symbolizing the excellence as a public building—and all this layered by the presence of three entirely separated circulation networks but all interfacing at the courtrooms. The morphologies that can resolve these complexities are not many. Mies took Waterhouse's architectural lessons constructed for different needs and user groups—at the time the "dirty" public required a separate network as different types of lawyers to demarcate their power within the rising complexity of the building type—and consolidated them almost in a platonic fashion in the clear architectural element of the ring showcasing a pristine form to be copied and transformed all over US courthouse designs since the Dirksen Courthouse. The majority of these recent designs could be understood as variations of the planar ring morphology investigated in this work through the formalization of the Dirksen Courthouse.

More interestingly, there are few foregrounding designs that feature more elaborate variations of the ring morphology in which the rings are three-dimensional allowing more sectional possibilities in configuring the organization of the spaces—such as the Austin US Courthouse in Austin, Texas designed by Mack Scogin Merrill Elam Architects (2012). Mies' design process of the Dirksen Courthouse formalizes the employment of the ring morphology and the Dirksen grammar presented here enables extensive explorations of possible schematic compositions of courtroom plate. Unlike the rules in Stage 3, 4 and 5 which capture specific design features of the Dirksen Courthouse, the rules in Stage 1 and 2 describe an essential generative logic of the underlying compositional structure of the ring morphology. Under the premise, these particular rules are to be evaluated in terms of their generality towards describing a broader corpus of contemporary courthouse designs and the grammar is to evolve towards a generative theory of courthouse building type by adding, subtracting and editing rules based on the insights from the evaluation. In this latter sense, the body of the work presented here provides the background for more general work on the formal specification of the contemporary courthouse design to be taken on in future work.

Acknowledgements We would like to thank Robert Andrukonis and Fred Miller at the United States General Services Administration for their overall insights in the architecture of contemporary courthouses, and also, Thomas Grasl for his helpful suggestions and generous support for the software implementation of the Dirksen grammar presented in this paper.

References

Administrative Office of the United States Courts. 2007. *US Courts Design Guide*. Washington DC: Administrative Office of the United States Courts.

Architectural Design. 1964. Recent Work of Mies v. der Rohe in the US. *Architectural Design*. January, 64.

Architectural Record. 1965. Mies Design Federal Center in Chicago. *Architectural Record*. March, 65.

Blaser, Werner. 1977. *After Mies: Mies van der Rohe, Teaching and Principles*. New York: Van Nostrand Reinhold.

Blaser, Werner. 1997. *Mies van der Rohe*. Basel: Birkhäuser.

Byard, Paul. 2006. Reading the Architecture of Today's Courthouse. In *Celebrating the Courthouse: A Guide for Architects, Their Clients, and the Public*, ed. S Flanders, 133–151. New York: W W Norton.

Carter, Peter. 1999. *Mies van der Rohe at Work*. London: Phaidon.
Cohen, Jean-Louis. 1996. *Mies van der Rohe*. London: Spon.
Economou, Athanassios, and Thomas Grasl. 2018. Paperless Grammars. In *Computational Studies on Cultural Variation and Heredity*, ed. Ji-Hyun Lee, 139–160. Singapore: Springer.
Courtsweb: A Visual Description of Contemporary US Courthouses. 2015. United States General Services Administration. https://publiccourts.gsa.gov/courtsweb/. Accessed 13 November 2017.
Grasl, Thomas, and Athanassios Economou. 2013. From Topologies to Shapes: Parametric Shape Grammars Implemented by Graphs. *Environment and Planning B: Planning and Design* 40:905–922.
Greene, Frank. 2006. The Image of Courthouse. In *Celebrating the Courthouse: A Guide for Architects, Their Clients, and the Public*, ed. S Flanders, 63–80. New York: W W Norton.
Gruzen, Jordan, Cathy Daskalakis, and Peter Krasnow. 2006. The Geometry of a Courthouse Design. In *Celebrating the Courthouse: A Guide for Architects, Their Clients, and the Public*, ed. S Flanders, 83–90. New York: W W Norton.
Kalay, Yehuda. 2004. *Architecture's New Media: Principles, Theories, and Methods of Computer-Aided Design*. Combridge: MIT Press.
Lambert, Phyllis. 2001. Mies Immersion. In *Mies in America*, ed. Phyllis Lambert, 133–589. New York: H N Abrams.
Lee, Antoinette. 2000. *Architects to the Nation: The Rise and Decline of the Supervising Architect's Office*. New York: Oxford University Press.
Leers, Andrea. 2006. Urban design and the courthouse: How sites shape solutions. In *Celebrating the courthouse: A guide for architects, their clients, and the public*, ed. S Flanders, 110–132. New York: W W Norton.
March, Lionel, and Philip Steadman. 1974. *The Geometry of Environment: An Introduction to Spatial Organization in Design*. Cambridge: MIT Press.
Mies van der Rohe, Ludwig. 2007. On Architecture as Language (recorded in Chicago, 1956). In *Bauhaus Reviewed (1919–1933)*. Norfolk: LTM Recordings.
Mies van der Rohe, Ludwig, Arthur Drexler, and Franz Schulze. 1992. *The Mies van der Rohe Archive: An Illustrated Catalogue of the Mies van der Rohe Drawings in the Museum of Modern Art*. New York: Garland Publishing.
Mitchell, William. 1977. *Computer-Aided Architectural Design*. New York: Petrocelli/Charter.
Mitchell, William. 1986. Formal Representations: A Foundation for Computer-Aided Architectural Design. *Environment and Planning B: Planning and Design* 13 (2):133–162.
Mulcahy, Linda. 2011. *Legal Architecture: Justice, Due Process and the Place of Law*. London: Routledge.
Phillips, Todd. 2006. Courthouse Design at a Crossroads. In *Celebrating the Courthouse: A Guide for Architects, Their Clients, and the Public*, ed. S Flanders, 202–223. New York: W W Norton.
Phillips, Todd, Stephen Kliment, and Michael Griebel. 2003. *Building Type Basics for Justice Facilities*. Hoboken: John Wiley.
Progressive Architecture. 1965. Interior for the Federal Government. *Prograssive Architecture*. July, 65.
Resnik, Judith, and Dennis Curtis. 2011. *Representing Justice: Invention, Controversy, and Rights in City-States and Democratic Courtrooms*. New Haven: Yale University Press.
Robinson, Judith, Stephanie Foell, and United States General Services Administration. 2003. *Growth, Efficiency and Modernism: GSA Buildings of the 1950s, 60s, and 70s*. Washington DC: United States General Services Administration.
Seale, William. 2006. American Vernacular: The Courthouse as a Building Type. In *Celebrating the Courthouse: A Guide for Architects, Their Clients, and the Public*, ed. S Flanders, 35–62. New York: W W Norton.
Spaeth, David. 1985. *Mies van der Rohe*. New York: Rizzoli.
Speyer, A James, and Frederick Koeper. 1968. *Mies van der Rohe*. Chicago: Art Institute of Chicago.
Stiny, George. 2006. *Shape: Talking About Seeing and Doing*. Cambridge: MIT Press.
Stiny, George, and William J Mitchell. 1978. The Palladian Grammar. *Environment and Planning B* 5:5–18.
Vanderbeke, Patricia. 1993. Awaiting Judgement. *Inland Architecture*. May/June, 93.
Woodlock, Douglas. 2006. Drawing Meaning from the Heart of the Courthouse. In *Celebrating the Courthouse: A Guide for Architects, Their Clients, and the Public*, ed. S Flanders, 155–167. New York: W W Norton.

James Park is a PhD Student in the School of Architecture at the Georgia Institute of Technology. His research investigates courthouses as a building type and focuses on designing and implementing a generative description of the building type in the form of a shape grammar. James is a research assistant at the Shape Computation Lab and his contributions include the administration of a funded research project, Courtsweb: A visual database of contemporary US courthouses, in collaboration with GSA and US Courts; generative and parametric modeling in formal design studies; and design and implementation of various database and web applications. He is an instructor for the series of courses on computational media and modeling at the School of Architecture and a teaching assistant for the Georgia Tech Architectonics in Greece and Italy Study Abroad Program. James holds a BSArch and MArch from the Georgia Institute of Technology.

Athanassios Economou is Professor in the College of Design at Georgia Institute of Technology. Dr. Economou's teaching and research are in the areas of shape grammars, computational design, computer-aided design and design theory. He is the Director of the Shape Computation Lab, a research group that explores how the visual nature of shape can be formally implemented with new software technologies to assist seeing and doing in design in new ways. Dr. Economou holds a Diploma in Architecture from NTUA, Athens, Greece, an MArch from USC, and a PhD in Architecture from UCLA.