Le Corbusier's Museum of Unlimited Extension: Spirals and Occlusion Maps

This paper attempts to show how an understanding of contemporary digital technologies and procedures can inform historical understanding of architectural works.

MIKE CHRISTENSON

North Dakota State University

INTRODUCTION

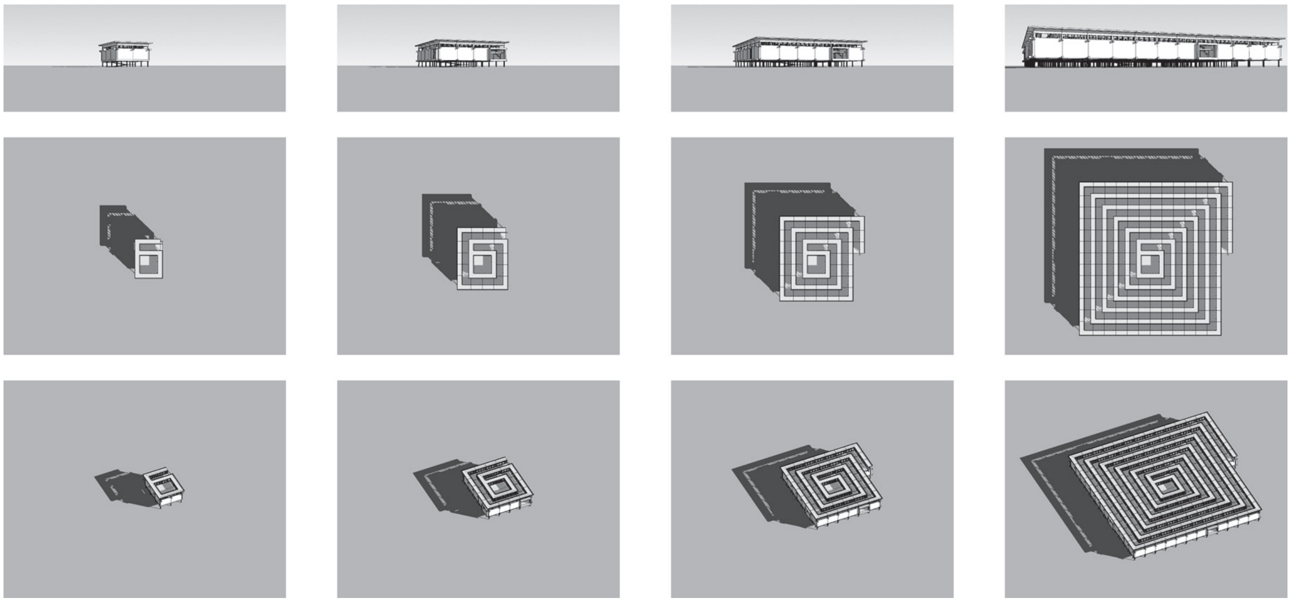
A "historical understanding of an architectural work" does not necessarily mean an understanding of the cultural surroundings and background in which a project was developed and executed. In the context of this paper, it rather refers to the deployment of contemporary digital technologies as a component of historical analysis. The results of this study are not offered either as a comprehensive analysis of a work or as an exposé of the original designer's methods and assumptions, but instead, as an example of a methodology which is uniquely capable of revealing and disclosing insight into the latent forms and patterns present in historical works.

In this sense, the paper can be seen as part of the larger project of *architectural epistemology*—that is, the study of the ways in which information about architecture is structured, developed, and disseminated. In particular, the paper inquires into the possibility of contemporary digital technologies for analysis, bringing to bear upon historical analysis a set of questions which while originating with the software products of their own time, are nevertheless capable of structuring meaningful and relevant observations on historical works.[1]

Specifically, the paper addresses the possibility of algorithmically modeling the formal structure as well as the "structure of visibility" of a group of projects designed by Le Corbusier throughout the twentieth century. Although Le Corbusier's own approach to designing these projects can be defined as algorithmic, the primary goal of the paper is not to shed new light on Corbusier's approach, but rather to illustrate the usefulness of new technologies on analysis—a usefulness which should extend beyond specific buildings or architects.

BACKGROUND

Le Corbusier, in his *Complete Works 1938–1946,* lamented that modern times had not yet come to beneficial terms with the problem of the growth of buildings.[2] It was a problem that he chose to address over several decades, first proposing his own solution in the project he called *Musee a Croissance Illimitee* or the Museum of Unlimited Extension. The project (Figure 1) began as a simple core, to which square-plan bays would be added incrementally around the building's perimeter, maintaining a toplit condition throughout the main gallery spaces.



1

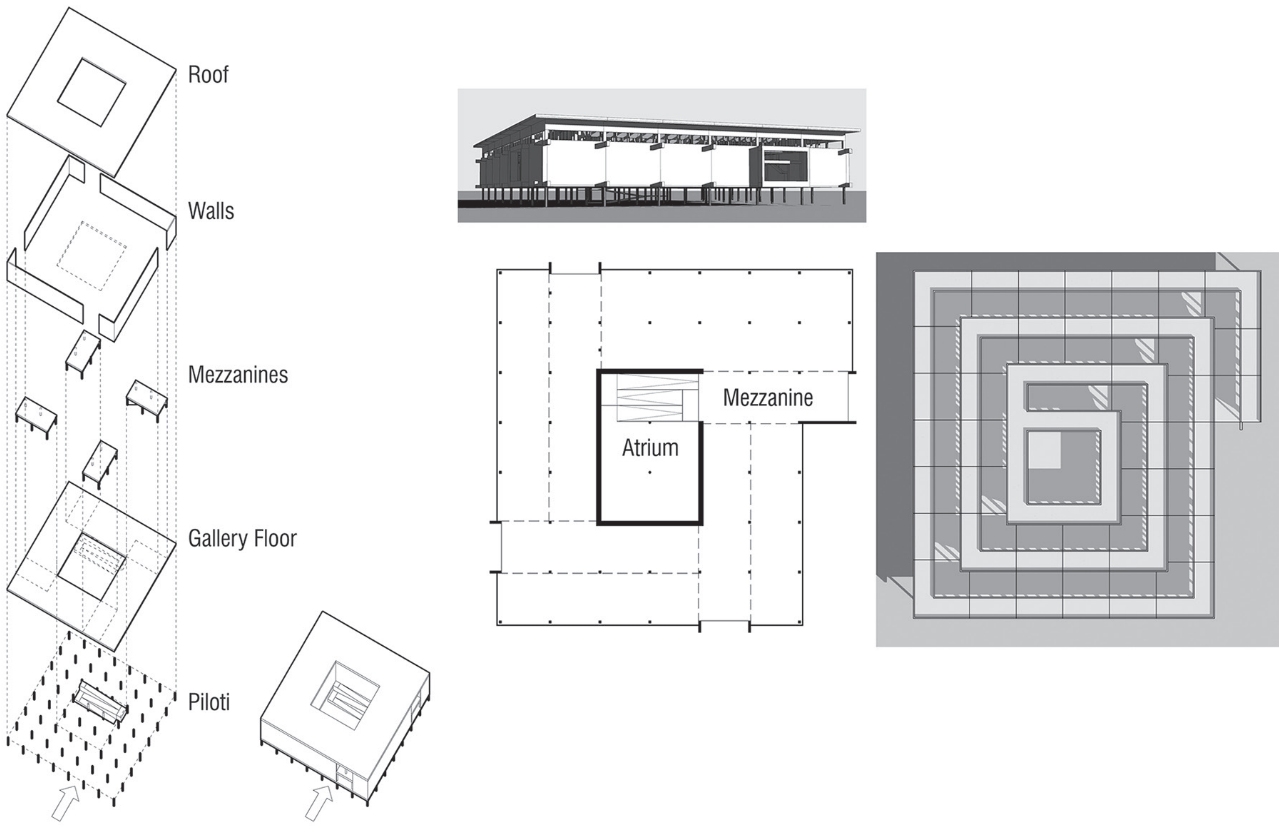
Le Corbusier developed the concept for the Museum of Unlimited Extension over a forty-year period. The concept has its roots in his project for the *Mundaneum,* or World Museum, which he proposed as an ascending ramp in the form of a square spiral, resulting in a form that has been called a "helicoidal ziggurat."[3]

As the concept matured, it resolved and flattened into a one-story gallery volume, square in plan, elevated above ground on a field of *piloti*. An atrium volume at the center of the square would contain a switchback ramp providing access to the gallery volume. The gallery itself would be organized as a square spiral penetrated by four mezzanine volumes (Figure 2). Le Corbusier envisioned these mezzanines as a kind of navigational aid to the museum, providing the visitor on each circuit of the main volume four views to the exterior garden and, in the opposite direction, views to the interior central atrium. In Le Corbusier's view, these mezzanine volumes would allow the museum to expand to a large extent without assuming the character of a labyrinth.

Le Corbusier's design for the Museum of Unlimited Extension was tested in several projects, built and unbuilt. Among the early projects to test the concept was a 1939 proposal for a museum at Skikda (formerly Philippeville), Algeria.[4] In the Skikda project, the building is set within an urban site, the field of *piloti* and the ascending ramp leading to the main museum floor. The published illustrations of the Skikda project make it quite clear that the museum would always exist in a state of suspended completion. Like the groove on a phonographic record, the path of Skikda's spiraling galleries would never have doubled back on itself to complete a revolution. The ring would have come to a definite end, but this end would always have awaited a new extension in the form of a square bay.

Figure 1: The Museum of Unlimited Extension.

In particular, Le Corbusier saw his solution to the "problem of the growth of buildings" as one which could be limited to a small set of building elements: a post, a beam, a ceiling, and lighting elements for day and night. This small set of elements was intended to be used repeatedly in the same way around the ever-expanding perimeter of the building, each time being assembled into a simple square bay.



2

Buildings based on the concept for the Museum of Unlimited Extension were constructed twice in India (Ahmedabad and Chandigarh) and once in Japan (Tokyo), in all three cases built to house art galleries.[5] The three buildings are similar in size and in organization; the most marked differences are that the atrium is open to the sky in the Indian buildings but roofed in Tokyo. Also, the concrete exterior of the Tokyo building sets it apart from the brick buildings in Ahmedabad and Chandigarh.

Arguably, Le Corbusier understood the design and construction of the museum in what we would today call algorithmic terms. He set out a simple rule for construction and allowed the rule to run its course. However, as we will see, an algorithmic approach to design does not account for the entirety of the museum's structure.

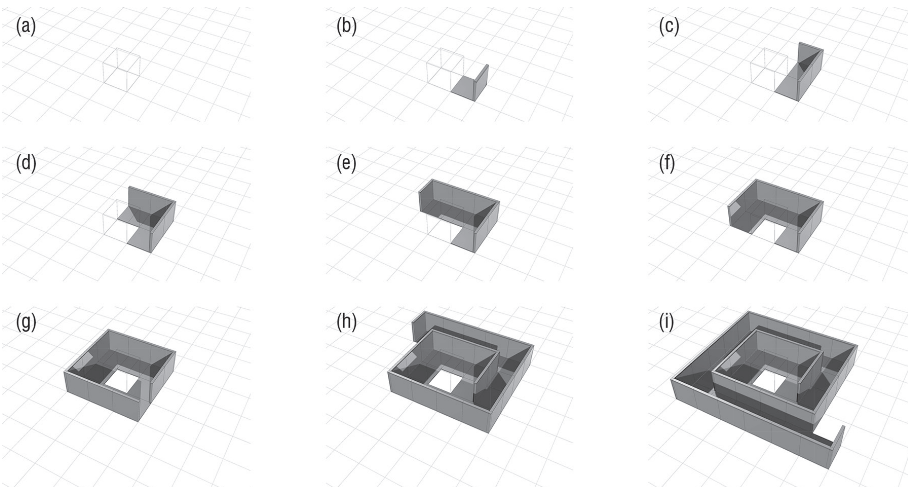
As the building was understood to expand without limit, view from the interior to the exterior remained an important issue for Le Corbusier. The structure of the museum enables two distinct experiences of viewing the horizon: first, an initial condition at ground level, where the horizon is visible from within the open field of *piloti*; and subsequently from within the toplit gallery volume, where the horizon is seen through rectangular openings in the exterior walls beneath the mezzanines. Although Le Corbusier designed the museum to be extended through addition to an arbitrarily large size, his proposal for extension ensured that these two distinct experiences would be maintained in their basic form, although altered in their specific configuration as the museum expanded.

Figure 2: Concept and Structure of the Museum.

ALGORITHMICALLY GENERATING THE SPIRAL STRUCTURE

Contemporary algorithmic processes and digital technology can be brought to bear on the question of generating the structure of the Museum of Unlimited Extension. First, consider that an algorithm for constructing the Museum's spiral structure can be *locally* or *globally* referential. In general, a locally referential algorithm considers each successive one-bay addition as a unique situation for evaluation, beginning with the core of the building and expanding outwards, while a globally referential algorithm aims to construct the entire spiral structure as an expression of a set of simple rules. In either case the limits are taken to be arbitrarily extensible.

Consider the following conditions for a locally referential algorithm. A grid of interval *L* is established from an origin point on the *xy* plane. The core of the building is represented by a single, empty cubical volume of side length *L* placed with a corner at the grid's origin point, as shown in Figure 3(a). The algorithm evaluates successive grid squares individually to determine whether one of two types of structure will be built—either a wall structure or a corner structure. These structures are designed to occupy cubical volumes of side length *L,* as shown.



3

Figure 3. Placement of wall and corner structures.

In general, the algorithm tests the square by inspecting the occupied/unoccupied state of the grid square "ahead and to the left". This is done by directing inquiry along a rotatable vector designated V_1.

The algorithm proceeds as follows:

0 The placement coordinates are set to *x*=*L* and *y*=0 and an initial wall structure is placed (Fig. 3 (b)).

1 Test whether the grid square "ahead and to the left" is unoccupied.

2 if unoccupied:

- 1 increment placement coordinates (*x, y*) by *L* units along V_1.
- 2 PLACE corner structure (Fig. 3(c)).
- 3 rotate V_1 by 90 degrees counterclockwise.
- 4 increment placement coordinates (*x, y*) by *L* units along V_1.
- 5 return to [1].

3 else:

1 increment placement coordinates (*x, y*) by *L* units along V_1.

2 PLACE wall structure (Fig. 3(d)).

2 return to [1].

Note in particular that corner structures are placed only when the relevant grid square is empty, and only in this case is V_1 rotated, i. e., when a finite sequence of wall structures comes to an end at the building corner, the algorithm "turns" by 90 degrees to continue its inspection. Figure 3 shows the repeated application of the algorithm, modeled in Rhino.

Alternatively, an algorithm can be defined globally, for example using Grasshopper. A Grasshopper definition to construct the spiral museum can begin by defining a list with the following structure: (1, 1, 2, 2, 3, 3, 4, 4, ...).

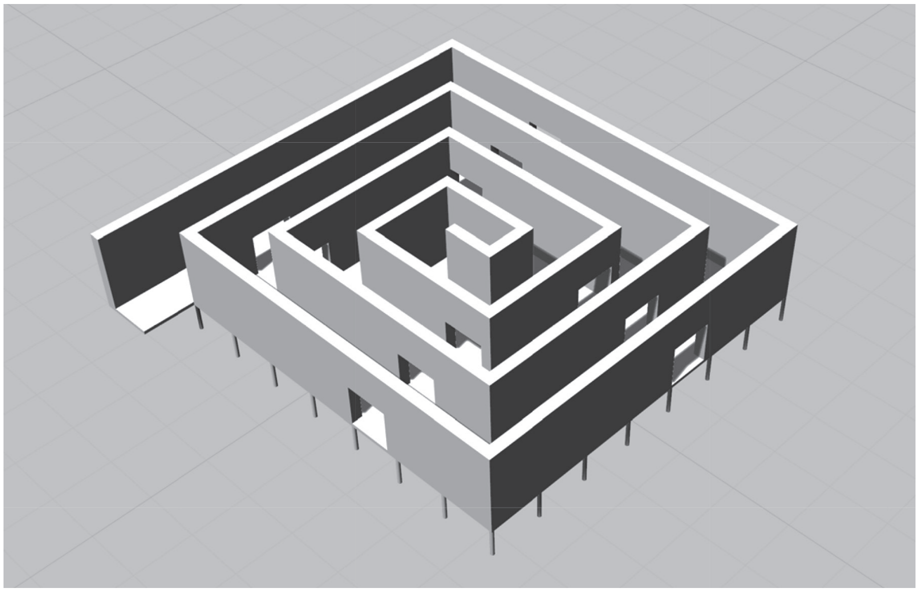
This list is used to construct a series of walls of increasing length (i. e., two walls of length 1, followed by two walls of length 2, etc.), each of which is rotated by successive increments of 90 degrees counterclockwise and moved by (*x, y*) coordinates determined by variants of the basic list (Table 1).

WALL LENGTH	MOVE_X	MOVE_Y	ROTATE
1	0	0	0
1	1	0	90
2	1	1	180
2	-1	1	270
3	-1	-1	0
3	2	-1	90
4	2	2	180
4	-2	2	270
5	-2	-2	0
5	3	-2	90
6	3	3	180
6	-3	3	270
7	-3	-3	0
7	4	-3	90
8	4	4	180

Table 1. Parameters for implementation of square spiral algorithm in Grasshopper.

The Grasshopper definition as written includes input parameters defining the planar extent of the spiral, wall thickness, and wall height.

Beyond the algorithmic generation of the building's spiral structure using either of the two methods described, a viable model for testing Le Corbusier's algorithmic attention to visibility (see following section) must be (a) raised on a field of *piloti* and (b) penetrated with mezzanine volumes (Figure 4).



4

Although either the local or global algorithmic method fairly replicates the structure of the Museum, there are certain issues which prevent a complete and formal characterization of Le Corbusier's 1939 definition of the Museum of Unlimited Extension in algorithmic terms. First, Le Corbusier's design, while indeed generally algorithmic in its structure, fails to account for the difference between a "regular" bay and a "corner" bay—i. e. a bay with one exterior wall as distinct from one with two exterior walls. In his 1939 definition the distinction is simply glossed over. Furthermore, Le Corbusier is not explicit concerning the originating condition of the expanding museum—we can assume is it the central atrium in some form, but is that originating condition an unwalled atrium (as an "ideal cube") or a walled one (as built in the actual structures)? In this sense his description and diagrams are unclear.

ALGORITHMICALLY GENERATING AN OCCLUSION MAP

Le Corbusier's attention to the need for navigation in the museum is critical to its overall design. Recall that Le Corbusier had proposed four mezzanine volumes extending outward from the central atrium to the exterior garden. Although these mezzanine volumes were not explicitly defined in his written definition of the problem, the models and drawings accompanying his written proposal make their character and structure clear. The four mezzanines define a clear structure of visibility which repeats on an expanding scale as the museum expands outward, each time directing views to the garden outside, i. e., the horizon, and to the central atrium.

Considering how Le Corbusier's structure of visibility could be understood algorithmically suggests the use of isovist mapping. Here, an "isovist" is simply a diagram representing the possibility of view to the horizon over a 360-degree field of vision, based on a station point. A simple Grasshopper definition can be used to create an *occlusion map,* i. e., a distributed field of plan isovists, as a device for representing an observer's view of the occluded horizon

Figure 4. Algorithmically generated square spiral raised on *piloti* and penetrated with mezzanine volumes.

from each of several points in a spatial field.[6] The algorithmic construction of the occlusion map establishes a series of points within a field, each of which corresponds to an occupant's position at a moment in time; based on each station point, a two-dimensional isovist is constructed by summing lines of sight to an arbitrarily established horizon, except where the view of the horizon is occluded by an intervening element. This method recalls Batty's isovist-construction procedure involving a "walking agent" encountering obstacles.[7] The closer an isovist is to a complete, filled-in circle, the more the view from that isovist's station point consists of an unobstructed horizon in all directions.

A Grasshopper definition can be written to construct a square grid, at each corner of which an isovist is generated using a radius 10 times the size of the grid interval. Specifically, Grasshopper's Isovist component plots the points of intersection between (a) lines radiating from the point at the isovist center and (b) Rhino curves representing walls. Each isovist is then scaled to 1/20th of its constructed size using its own center as a base point, resulting in an occlusion map of the form shown in Figure 5.

5

CHANGES IN BUILDING EXTENT

As the square spiral museum grows in extent with the addition of individual bays around the perimeter, the occlusion map registers the changes in visibility, as shown in Figure 5. In interpreting these maps, which consist of isovists deployed in a grid, recall that an isovist appears as a full, shaded circle only in the case of an unobstructed view of the horizon. An isovist which appears as a quarter-circle represents a view from a three-quarters-enclosed area. (This is the typical condition at the mezzanine windows looking out to the garden.) An isovist equivalent to a small dot represents a location from which no view of the horizon is possible (e. g., within the central atrium). An isovist which appears in these small-scale maps like a horizontal or vertical bar represents a "tunnel" view of the horizon from the respective station point. In these maps, note how the mezzanine volumes retain their characteristic "tunnel effect" on visibility as the museum expands arbitrarily outward. Even as the views within the main gallery space are typically inward-focused (i. e., not providing views of the horizon), the mezzanine volumes provide clear lines of sight reinforcing Le Corbusier's original concept for a structure of visibility aiding in navigation of the square-spiral museum.

DISCUSSION AND FUTURE WORK

This paper has attempted to show how the understanding of contemporary technologies deepens the understanding of what Le Corbusier sought to achieve: a "solution to the problem of the growth of buildings." Although Le Corbusier did not formulate his constructional algorithm as strictly as the ones described in this paper, his thinking was algorithmic to a degree, as evidenced by his attention to the repetitive application of simple rules to create an arbitrarily large structure. Moreover, his thinking about visibility and navigation can be shown to be susceptible to an algorithmic thought process, as illustrated by the occlusion maps which show the preservation of a basic structure of visibility even as the museum expands arbitrarily.

Figure 5. Occlusion maps at building size 8, 16, 32, and 64.

Yet, while exploring the Museum of Unlimited Extension through contemporary algorithmic and digital techniques sheds some new light on Le Corbusier's thought and design process, the primary goal of this paper is not to recruit Le Corbusier as a progenitor of contemporary digital tools, but is rather more general: that is, to demonstrate through example the applicability and usefulness of contemporary tools to historical analysis.

Thus, while future work in this project is to some extent concerned with the specificity of Le Corbusier's work, in particular with comparing the algorithmic structure of (a) spiral generation processes and (b) occlusion map construction, towards a near-term goal of formulating a single algorithm capable of simultaneously generating the building's spiral structure and an occlusion map of that structure, the larger project of this paper as it relates to architectural epistemology is to highlight the capability of digital tools of revealing latent attributes of historical architectural works. To this end, future work is specifically directed toward the incorporation of the methods described here into architectural pedagogy. Two parallel avenues, related but distinct, are being explored and tested: first, the placement of historical works as subject matter in an undergraduate course dedicated to the instruction of digital technology, and second, the continuing development of digital technology as one of several modes for analyzing and understanding historical precedent within the studio environment.[8]

ENDNOTES

1. A similar approach is described and developed in Andrzej Piotrowski (1997), "The Structures of Memory: New Modes of Depicting Existing Architecture," in *Architecture: Material and Imagined (Proceedings of the 85th ACSA Annual Meeting and Technology Conference),* ed. Lawrence W. Speck, 529-534 (Association of Collegiate Schools of Architecture, Washington, DC).

2. Le Corbusier, Jeanneret P, Boesiger W (1946), *Œuvre Complète, 1938–1946* (Éditions d'architecture, Erlenbach-Zurich).

3. For a description of the Mundaneum project, see Anthony Moulis (2002), "Le Corbusier, the Museum Projects, and the Spiral Figured Plan," in *Celebrating Chandigarh,* ed. Jaspreet Takhar, 350-352 (Mapin Publishing, Ahmedabad, India).

4. For drawings and a description of the Skikda proposal, see Le Corbusier, Jeanneret P, Boesiger W (1946), *Œuvre Complète, 1938–1946* (Éditions d'architecture, Erlenbach-Zurich).

5. Mike Christenson (2014), "Isovist-Based Occlusion Maps Representing Critical Variations in Le Corbusier's Museum of Unlimited Extension," *Environment and Planning B: Planning and Design* 41 (1), 39–52.

6. For a discussion of the *occlusion map,* see Mike Christenson (2010), "Registering visual permeability in architecture: Isovists and occlusion maps in AutoLISP," *Environment and Planning B: Planning and Design* 37(6), 1128–1136.

7. Michael Batty (2001), "Exploring isovist fields: space and shape in architectural and urban morphology," *Environment and Planning B: Planning and Design* 28(1): 123–150.

8. Both courses are under development by this paper's author at North Dakota State University. Ideas relevant to the development of both courses are explored in Mike Christenson (2015), *Beginning Design Technology* (Routledge, New York).