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Geometric Operations in Mario Botta's Architectural Work

Francesca Ronco[1] · **Giulia Bertola**[2] · **Enrico Pupi**[3]

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Abstract
This paper investigates the role of primary plane figures, primary solids, and geometric operations in Mario Botta's architectural works during fifty years of his career. Through the selection of three case studies, the research allows the creative process to be discretized and analyzed from a geometric-mathematical point of view.

Keywords Mario Botta · Geometry · Geometric analysis · Symmetry · Transformations

Introduction

The objective of the present work is to interpret and represent via graphical analysis the geometric aspects that govern the composition and shape of Botta's architecture. It represents an analytical work at an early stage, conducted on 74 pieces which compare different building models, thus highlighting the role of geometry as a fundamental tool. The process begins with analyzing his work, identifying a series of geometric figures and solids, frequently found in his architecture, with a digital volumetric reconstruction. At this stage, examining the master's repertoire, our work focuses on three buildings: the cymbalist synagogue in Tel Aviv; the single-family house in Riva San Vitale; and the church of San

✉ Francesca Ronco
fronco@doctor.upv.es

Giulia Bertola
gbertol@doctor.upv.es

Enrico Pupi
enrico.pupi@polito.it

[1] D. Expresión Gráfica Arquitectónica - Universitat Politecnica de Valencia, Camino de Vera, s/n, 46022 Valencia, Spain

[2] D. Expresión Gráfica Arquitectónica - Universitat Politecnica de Valencia, Camino de Vera, s/n, 46022 Valencia, Spain

[3] DAD - Department of Architecture and Design, Politecnico di Torino, Viale Pier Andrea Mattioli, 39, 10125 Turin, Italy

Giovanni Battista in Mogno. They are chosen while condensing the geometric operations that are found in Botta's production. The three architectural structures were investigated from drawings on a graphic scale, published in *Mario Botta. Architecture 1960–2010* (2010) according to these parameters: geometric transformation operator, primary plane figure in plan, primary solids, and geometric operations (boolean, transformation, cuts and sections).

The Research

Preliminary Studies

The study of buildings as products of design requires theories and tools that describe topo-geometric properties as well as the interaction between spatial and geometric systems (Psarra 2017). Architects identify systems by combining geometric forms that give buildings their specific appearance.

The description of form and space is a description of composition as a process of transformation. Formal and spatial patterns interact through geometric properties; the designer's syntactic and semantic rules mediate the relationship between form and function. As Mitchell (1990) argues, the architect's task is to give form to buildings according to their function and then relate the two.

How architecture is given form and experienced in space elicits the question: how can geometric-formal properties of an architectural work be described analytically?

In this paper, the authors attempt, through digital modeling, to compare and classify Botta's architecture and establish relationships between different geometric entitites and their compositional rules. This provides recognition, decomposition, and recomposition of various elements and reconstruction towards possible variants and invariants (Spallone and Vitali 2020).

To understand the compositional principles underlying Botta's architectural projects, it is essential to start with certain assumptions, highlighted by Psarra (1997); this constituted an essential reference to draft the present contribution:

- the more geometric properties remain unchanged, the less tension is created between its parts, and structural unity will be achieved to facilitate intelligibility of a single reading;
- the composition is dominated by an explicit syntax, established early in the transformation;
- the spatial narrative is subject to the formal model.

His architectural production and training were inextricably linked to the rationalist experience of Le Corbusier and Louis I. Kahn, aiming for continuous refinement of simple, elementary forms. This simplification is linked to his views on tradition, to refer to the Modern Movement and the Palladian legacy, from which regulatory layouts and composition of solids were often inspired. Botta

intuitively uses geometry as a tool to control form, by which he can describe the connection of his buildings to function and context (Sala and Cappellato 2003).

Geometrical Analysis of Mario Botta's Architectural Works

In Botta's design, the geometric foundation is understood as a source of inspiration and only later as support of the creative process and a matrix of forms. (Studio Botta 2010). The plan represents as it is combined with volume, the starting point, the definition which constitutes a central moment within the composition process.

"The plan defines the volume to such an extent that other elements of the project—the section, the elevation—impose themselves as necessary consequences." (Trevisol 1982: 98).

The process leads to a definition of the project, always starting from the definition of a primary geometric entity, which develops and changes, but always remains legible. Generally, a main volume shapes the whole and smaller volumes are distinct from it. When there are several volumes, their conjunction follows precise rules. Symmetry is the main rule of order (Sakellaridou 2000). The plan and volume form the basis and beginning of the design process, which involves geometric transformations, always related to context, function and light.

Drawing accompanies Botta's design process and becomes a key expression. The ultimate result is often intrinsically linked to initial intentions. However, there is a logical maturation throughout the process, as Botta never denies the principles from which he began, constituting a circular design process. His architecture, as Alessandra Coppa argues, prompts us to attend to the signs used as well as to their changes (Coppa 2007).

Starting from this assumption, the authors present three projects representative of geometric devices that recur as Botta's modus operandi. These are identified by analyzing his whole architectural production, the result of which is explicit in tabular form (Tables 1, 2, 3).

After an initial overall reconstruction of the artifacts and an identification of primary entities, the geometric operations that characterize their tectonics are discerned: Boolean unions (in blue), Boolean subtraction (in red), Boolean juxtaposition (cyan), cut/section (in yellow), and section transformation along a trajectory, called loft (in green) (Fig. 1).

Selected Case Studies

Design of residential buildings, concentrated in the early years of his career, provided a means for experimenting with the potential of variations in elementary forms of the square and circle as well as the cube and cylinder. In the 1979 monograph (Battisti and Frampton 1979), Botta collects in a single sheet the genetic patterns of twelve buildings designed in that period.

Table 1 Excerpt from the geometrical analysis table of Mario Botta's architectures: living spaces, collective living spaces, working spaces

Work	Site	Timing		Metric data		Primary geometric entities				Geometric operations					
		Design year	Construction year	usable Area [sq. m]	Volume [cu]	Transformation operator	n. of entities	Primary plane figure in plan	Primary solids	Function of space	n. of solids	Solid	Boolean operator	Transformation operator	Cut/ section
Living spaces															
Single-family House	Riva di San Vitale (Switzerland)	1971	1972–1973	220	1000	Similarity: scale 1 reduction;		Square	Parallelepiped	Lodge	1	Parallelepiped	Subtraction	–	–
										Terrace	2	Parallelepiped	Subtraction	–	–
										Skylight	1	Cylinder	Subtraction	–	–
										Footbridge	1	Parallelepiped	Juxtaposition	–	–
Single-family House	Stabio (Switzerland)	1980	1980–1981	295	1400	Axial symmetry	1	Circumference	Cylinder	Entrance	1	Parallelepiped	Subtraction		–
										Staircase	1	Cylinder	Union	Loft	
										Skylight	1	Polyhedron with triangular base	Juxtaposition	–	
Single-family House	Vacallo (Switzerland)	1986	1987–1988	310	2000	Axial symmetry	1	Triangle	Prism	Lodge	1	Parallelepiped with trapezoidal base	Subtraction	–	–
										Lodge	1	3D arches	Union	Translation	
										Terrace	1	portion of cylinder	Union	–	
										Skylight	1	Parallelepiped with triangular base	Juxtaposition	–	

Table 1 (continued)

Work	Site	Timing		Metric data		Primary geometric entities				Geometric operations					
		Design year	Construction year	usable Area [sq. m]	Volume [cu]	Transformation operator	n. of entities	Primary plane figure in plan	Primary solids	Function of space	n. of solids	Solid	Boolean operator	Transformation operator	Cut/ section
Collective living spaces															
Home for the elderly	Novazzano (Switzerland)	1992	1995–1997	3271	16,557	Axial symmetry	1	Circle	Cylinder	Housing	1	Cylinder	Subtraction	–	–
										Pilotis floor	1	Portion of cylinder	Subtraction	–	–
										Common spaces	1	Parallelepiped	Union	–	–
										Skylight	2	Portion of cylinder	Juxtaposition	–	–
Working spaces															
Building Ransila 1	Lugano (Switzerland)	1981	1982–1985	4,000	20,000	Axial symmetry along the diagonal	2	Rectangle	Parallelepipeds	Corner	1	Cube	Subtraction	–	–
										Porch	3	Parallelepiped	Subtraction	–	–
										Inner bow-window	8	Parallelepiped with trapezoidal base	Subtraction	–	–
Five continents center	Lugano (Switzerland)	1986	1989–1992	4300	13,000	Axial symmetry	1	Circumference	Cylinder	Square	1	Parallelepiped	Subtraction	–	–
										Staircase	1	Cylinder	Juxtaposition	–	–
										Corridors	3	Parallelepiped	Juxtaposition	–	–
										Roof	1	Straight prism with base composed by two arcs of circumference	Juxtaposition	Axial symmetry	–

Table 1 (continued)

Work	Site	Timing		Metric data		Primary geometric entities				Geometric operations					
		Design year	Construction year	usable Area [sq. m]	Volume [cu]	Transformation operator	n. of entities	Primary plane figure in plan	Primary solids	Function of space	n. of solids	Solid	Boolean operator	Transformation operator	Cut/ section
Greek National Bank	Atene (Greece)	1998	1999–2001	5000	28,900	Axial symmetry	1	Rectangle	Parallelepiped	Square	1	Parallelepiped	Subtraction	–	–
										Covered space	1	Parallelepiped	Subtraction	–	–
										Auditorium	1	Portion of prism with octagonal base	Union	–	–
										Skylight	6	Parallelepiped with triangular base	Juxtaposition	–	–

Table 2 Excerpt from the geometrical analysis table of Mario Botta's architectures: school and free time spaces, wineries, libraries, museums)

Work	Site	Timing		Metric data		Primary geometric entities			
		Design year	Construction year	Usable area [sq. m]	Volume [cu]	Transformation operator	n. of entities	Primary plane figure in plan	Primary solids
School and free time spaces									
Club House "Agorà"	Jeju Island (South Corea)	2006	208	1000	7000	Central symmetry	1	Square	Parallelepiped
Wineries									
Petra winery	Suvereto (Italy)	1999	2001–2003	7200	63,000	Axial symmetry	1	Circumference	Cylinder
						Axiality	2	Rectangle	Parallelepiped
Libraries									
Media Library	Villeurbanne (France)	1984	1985–1988	5580	18,000	–	1	Parallelogram	Parallelepiped
						Radial symmetry	1	Semi-circumference	Semi-cylinder
						Axial symmetry	1	Trapezoid	Parallelepiped
Museums									
Art Gallery Watari-um	Tokio (Japan)	1985–1988	1988–1990	627	3650	Axial symmetry, scaling	1	Triangle	Parallelepiped
MOMA Museum	San Francisco (USA)	1989	1992–1995	18,500	100,000	Axial symmetry	1	Rectangle	Parallelepiped
Leeum, Samsung Art Museum	Seul (South Corea)	1995–1997/2002	2002–2004	10,000	42,000	–	1	Rectangle	Parallelepiped
						–	1	Circle	Inverted cone

Table 2 (continued)

Work	Geometric operations					
	Boolean operator	Transformation operator	Cut/section	Function of space	n. of solids	Solid
School and free time spaces						
Club House "Agorà"	Subtraction	–	–	Square	1	Parallelepiped with square base
	Juxtaposition	–	Horizontal cutting plane	Roof	1	Pyramid
Wineries						
Petra winery	Subtraction	–	Oblique cutting plane (parallel to the hills' profile)	Entrance	1	Portion of ring
	Union	–	Prism with triangular base	Staircase	1	
Libraries						
Media Library	Subtraction	–	–	Entrance	1	Parallelepiped
	Subtraction	–	–	Inner courtyard	1	Cylinder
	Juxtaposition	–	–	Staircase	3	Cylinder
Museums						
Art Gallery Watari-um	–	Fillet	–	Staircase	1	–
	Subtraction	–	–	Entrance	1	Parallelepiped
	Subtraction	–	–	Display	2	Parallelepiped
	Subtraction	–	–	Window	1	Parallelepiped
	Juxaposition	–	–	Tecnical space	1	Parallelepiped
	Juxaposition	–	–	Tecnical space	1	Cylinder

Table 2 (continued)

Work	Geometric operations					
	Boolean operator	Transformation operator	Cut/section	Function of space	n. of solids	Solid
MOMA Museum	Subtraction	–		Square	1	Parallelepiped
	Subtraction	–		Exhibition	1	Parallelepiped
	Juxtaposition	–	45° cutting plane	Skylight	1	Cylinder
	Subtraction	–				
	Juxtaposition	–	–	Exhibition	2	Parallelepiped
Leeum, Samsung Art Museum	Subtraction	–	–	Exhibition	1	Parallelepiped
	Subtraction	Scaling	–	Exhibition	1	Parallelepiped
	Subtraction		–	Exhibition	1	Inverted cone

Table 3 Excerpt from the geometrical analysis table of Mario Botta's architectures: theaters, sacred spaces)

Work	Site	Timing		Metric data		Primary geometric entities				Geometric operations					
		Design year	Construction year	Usable area [sq. m]	Volume [cu]	Transformation operator	n. of entities	Primary plane figure in plan	Primary solids	Function of space	n. of solids	Solid	Boolean operator	Transformation operator	Cut/section
Theaters															
Theater and cultural center André Malraux	Chambéry (France)	1982	1983–1987	9800	82,000	–	1	Composition of rectangle	Composition of parallelepipeds	–	–	–	–	–	–
						–	1	Circle	Cylinder	Entrance to the hall	1	Prism with trapezoidal base	Subtraction	–	–
						–				Emergency stairs	2	prism with triiangular base	Juxtaposition	–	–
Sacred spaces															
San Giovanni Battista Church	Mogno (Switzerland)	1986–1992	1990–1996	123	1590	Axial and central symmetry	1	Ellypse	Cylinder	Main space	1	Parallelepiped with rectangular plan	Subtraction	Loft	Cutting plane with an inclination suitable for obtaining a circle
										Entrance and apse	1	Parallelepiped with square base	Subtraction		
										Niche	2	2 intersected cylinders	Subtraction		
										Apse	1	Parallelepiped	Union		
										Rampant arch	1	3D arch	Juxtaposition		
Synagogue Cymbalista	Tel Aviv (Istrael)	1996	1997–1998	800	7325	Bi-axial symmetry	1	Rectangle	Parallelepiped	Entrance	1	Prallelepiped	Subtraction	–	–
										–	2	Parallelepiped with square base	Subtraction	loft	–
							3	Circle	Cone	Tower	2	Cylinder	Union		–
										Roof	2	Parallelepiped with square base	Juxtaposition	–	–

Table 3 (continued)

Work	Site	Timing		Metric data		Primary geometric entities				Geometric operations					
		Design year	Construction year	Usable area [sq. m]	Volume [cu]	Transformation operator	n. of entities	Primary plane figure in plan	Primary solids	Function of space	n. of solids	Solid	Boolean operator	Transformation operator	Cut/section
Santo Volto church	Torino (Italy)	2001	2004–2006	26,300	125,000	Central symmetry	1	Circle	Cylinder	Church	1	Pyramid with polygon base (14 sides)	Subtraction	–	45° cutting plane
							7	Trapezoid	Parallelepiped with trapezoidal base	Roof	1	Inverted pyramid with polygon base (14 sides)	Subtraction	–	–
										Skylight	1	cylinder	Subtraction	–	–
							1	Rectangle	Parallelepiped	Chapel	7	Union of parallelepipeds	Union	–	–

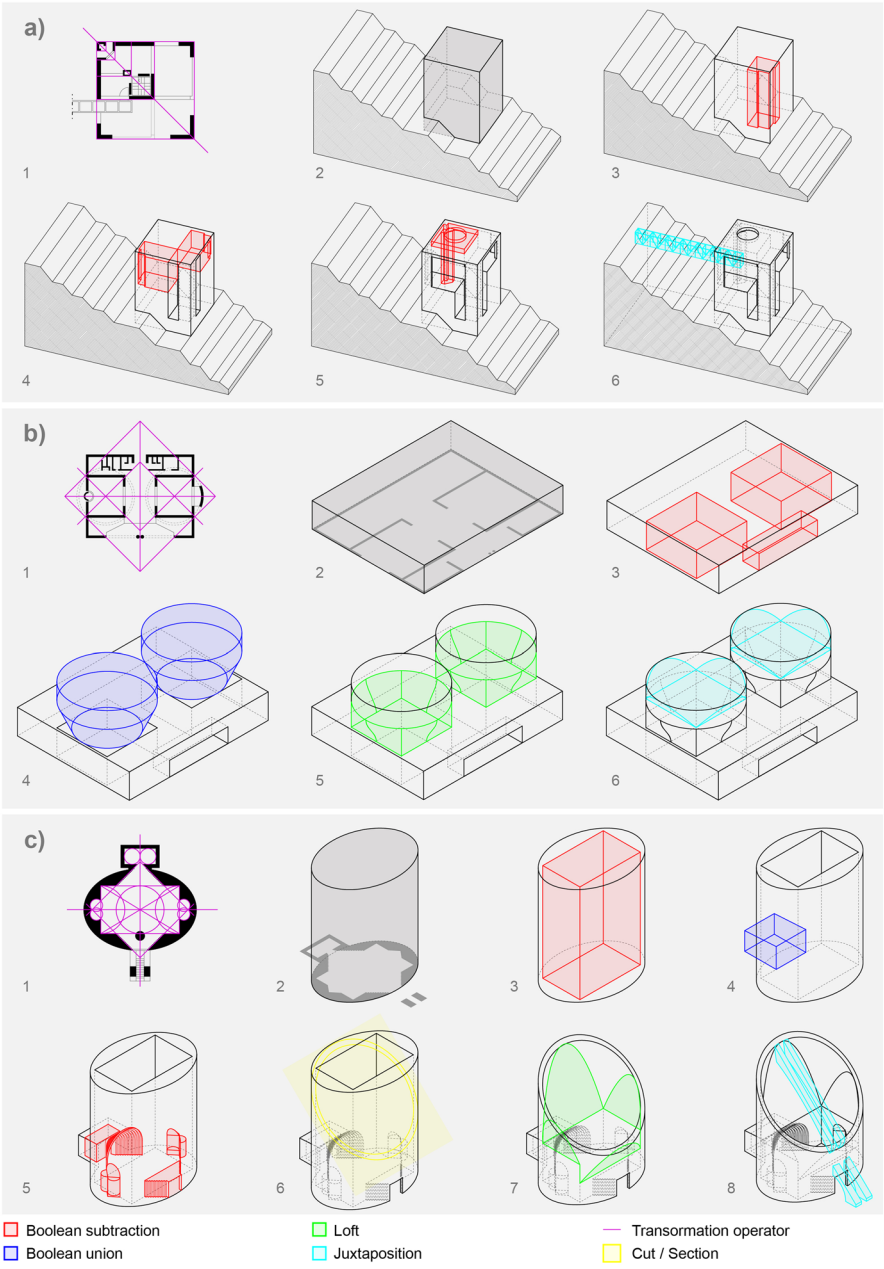


Fig. 1 Analysis of the generative geometric process of three architectures by Mario Botta: Riva San Vitale single-family house (1972–73), Cymbalista Synagogue and Jewish Heritage Center (Tel Aviv,1997–98) and St. John the Baptist Church (Mogno, 1990–96)

The single-family house in Riva San Vitale (1971–1973) has a square plan on which the parallelepiped volume is set, subject to boolean subtractions generating voids (Fig. 1a.3) and interior terraces (Fig. 1a.4) that relate to context. The building plans are set on a square base that varies from floor to floor. This figure recurs on all floors. We found it scaled several times along the diagonal to define the staircase body, the terrace, and volume at the entrance level. The skylight is obtained by subtracting a cylinder from the roof slab (Fig. 1a.5). A linear element, the footbridge, is inserted here, creating a plan with an orientation (Fig. 1a.6).

Clarity of volume and symmetry are elements that we can also find in the Cymbalista Synagogue and Jewish Heritage Center in Tel Aviv (1998), enhanced with symbolic value. The solid parallelepiped base with a flat profile, containing the entrance lobby and service spaces, symbolizing the human condition. At the same time, the vertical axes of the two symmetrical truncated towers represent the quest for the divine.

Analyzing the plan, it is possible to identify an axial pattern set at the center of the towers and draws cuts of the outer envelope (Fig. 1b.1). At the volumetric level, we see a series of operations: three parallelepiped volumes are subtracted (Fig. 1b.3) from the base parallelepiped (Fig. 1b.2), which define the entrance and square bases of the two symmetrical towers (Fig. 1b.4). A loft operation links them to roof circumferences (Fig. 1b.5), where the square slab is juxtaposed and inscribed in the edge circumference (Fig. 1b.6). The composition takes on a totemic aspect, the Botta's rationalism allowing for an abstraction of his work, symbolically aiming at the circle's squaring.

The church of San Giovanni Battista in Mogno (1986–96) represents another project in which there is a geometric transformation of the plan at different levels. The church space is tiny, and the geometric synthesis between figures of the rectangle, ellipse, and circle is composed with a symmetric balance.

It represents the ascent from the human dimension (space of the basement) to divine perfection (circular roof). Again, the center of the plan's volume represents the construction's starting point. The diagonals of the rectangle and square, rotated at 45°, pass through it (Fig. 1c.1). The rectangle represents primary footprints of volume subtraction (Fig. 1c.3). Then, the rectangular-based volume of the apse is added (Fig. 1c.4) and the volumes of the entrance, the apse and of the side niches are subtracted (Fig. 1c.5). The cylindrical volume with an elliptical base is then cut by a plane inclined to 45° at its axis (Fig. 1c.6), forming a circular roof. This circle is finally linked to the rectangle-shaped setting wall with a loft operation. Two arches are juxtaposed to the main solid, balancing the composition.

Conclusion

Our graphical analysis highlights and compares the geometric compositional processes of Botta's architecture.

The presented classification has been composed for multiple purposes, can originate different interpretations and indexing regarding the evolutions and transformations of geometries. It is therefore a dynamic tool, capable of generating

different fields of information, depending on the adopted reading key. It can generate considerations about the evolution of design poetics over time, about the relationship between geometry and function or between geometry and scale of intervention.

Parametric digital modeling tools can be useful for analyzing architecture with a geometric matrix by highlighting recurrences, variants, and invariants, and offering interpretative keys to the architectural design. The research offers broad perspectives in the Visual Programming Language landscape, to implement the geometry under study in the algorithmic system of Grasshopper (McNeel Rhinoceros plug-in).

Given these developments, we discern broad prospects for additional work. With this, it is plausible to investigate different aspects of the process: in the input phase for the generation of masses, in the processing phase for the geometric operations performed, and in the output phase for a mathematical/geometric analysis of assumed formal variations.

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Data availability The authors confirm that all data generated or analysed during this study are included in this published article.

Declarations

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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Francesca Ronco Architect and Ph.D. student. Since 2019, she has been collaborating with the Polytechnic University of Turin as a Research Fellow to re-evaluate and enhance the Modelling Laboratory (Mod Lab Design—DAD). She is a Ph.D. student at the Architecture, Building, Urban Planning and Landscape Programme of the Universitat Politècnica de València with a research on digital technologies applied to the accessible management of architectural and museum heritage. Since 2011, she has been working as a tutor for the courses "Laboratory of drawing and survey of architecture" and "Representation of the project" (Polytechnic University of Torino—DAD). From 2021, she collaborates as tutor at the introductory seminar "Inside the museum" and to the course "Representation of the project" (Polytechnic University of Torino—DAD).

Giulia Bertola Architect and Ph.D. student. Since 2019, she has been collaborating with the Polytechnic University of Turin as a Research Fellow to re-evaluate and enhance the Modelling Laboratory (Mod Lab Arch—DAD). She is a Ph.D. student at the Architecture, Building, Urban Planning and Landscape Programme of the Universitat Politècnica de València with a research path focused on studying plastic models for the narrative of architecture and the city and on innovative integrations of narrative devices between real and virtual. Since 2018, she has been working as a tutor for the courses "Laboratory of drawing and survey of architecture" and "Representation of the project" (Polytechnic University of Torino—DAD).Driven by a passion for drawing and "craftsmanship", she has always complemented her work with in-depth and personal research activity in different fields of visual expressions, such as painting, graphics, and illustration.

Enrico Pupi Architect, research fellow in "Advanced digital modelling for architectural and cultural heritage" at the Department of Architecture and Design (DAD) of the Politecnico di Torino, he has written articles on the realization of physical models for a wide range of purposes; specializes in geometric, parametric, informative, and algorithmic modelling and communication using physical models obtained through digital fabrication. He deals with a plurality of representation methodologies and techniques, both traditional and digital, which involved a wide variety of approaches, in analysis, restitution, interpretation, and presentation. Advanced skills in digital modelling and interoperability between software.