Image Schema and Ontology-Based Rules to support Planning Activities: a Study of the Urban Square

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Abstract
This contribution explores the connection between two research lines: one focused on creativity in the architectural design process, inspired by memories and constrained by rules, and the other on urban planning activities. The goal of establishing this connection is to investigate integrated decision-support systems in architecture and urban planning.

Keywords
Urban planning, architecture, creativity, applied ontology, image schema1

1. Introduction

This paper reports on a research path aimed to gather and manage heterogeneous knowledge in structured ways to improve accessibility, usefulness, clarity and inclusiveness. This effort intersects with at least two scientific research lines: the creative process in architecture, and the organization and planning of territory and environment. The final goal of this work finds its core motivation on the study of complex systems and, more specifically, of the city.

In the first research line, the aim is to provide architects with instrumental and cognitive tools to enrich and sustain their creative processes. It also seeks to help them to become more aware of their cognitive processes and the materials involved during the conception phase. This is achieved by managing memories, understood both as objects of memory and as rules that underlay architectural composition.

In the second research line, the focus is on empowering knowledge gathering and sharing to enhance management, clarification, and disambiguation throughout all phases of the planning process—from the initial analysis steps (of both hard and soft data) to participation phases, as well as decision-making and monitoring stages.

In both research lines, we found significant potential in using ontological analysis and methodologies from the applied ontology domain. These methods organize and make explicit the relationships between memory objects (here understood as knowledge objects [1]) and their attributes. It facilitates human-machine dialogue and exchanges, enabling powerful assistance in recalling "necessary materials" from memory during the creative process. Similarly, in the second research line, it supports the sharing of clarified and consistent knowledge among various agents involved in the planning process.

On another side, our research also explored the links across applied ontology and image schemas. We believe that integrating embodied knowledge, as explicated by image schemas, into ontological analysis can provide a stronger and more effective translation and understanding of the spatial

The Eighth Image Schema Day (ISD8), November 27-28, 2024, Bozen-Bolzano, Italy
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cognition mechanisms that occur during the creative design process. This concept was discussed in [2] and is briefly summarized in the next chapter.

The present contribution investigates a ring-like connection between these two research lines, specifically exploring the intuition of linking applied ontology and image schema methods to support decision-making in urban and territorial planning. Our goal is to develop integrated decision-support systems for architecture and urban planning by combining an ontology-based approach with image schemas.

Following this introduction, section two offers a brief description of how we employed an ontological rule-based analysis and image schema analysis to the architectural composition principle of the Raumplan. In section three, we summarize our research regarding the city through ontological layers. Section four introduces a key architectural element in the city: the urban square. Section five focuses on the comparison between the characteristics of two distinct squares, we argue for the application of image schemas and applied ontology in managing and representing knowledge within the urban planning process. Finally, section six presents our conclusions and follow-ups for future research.

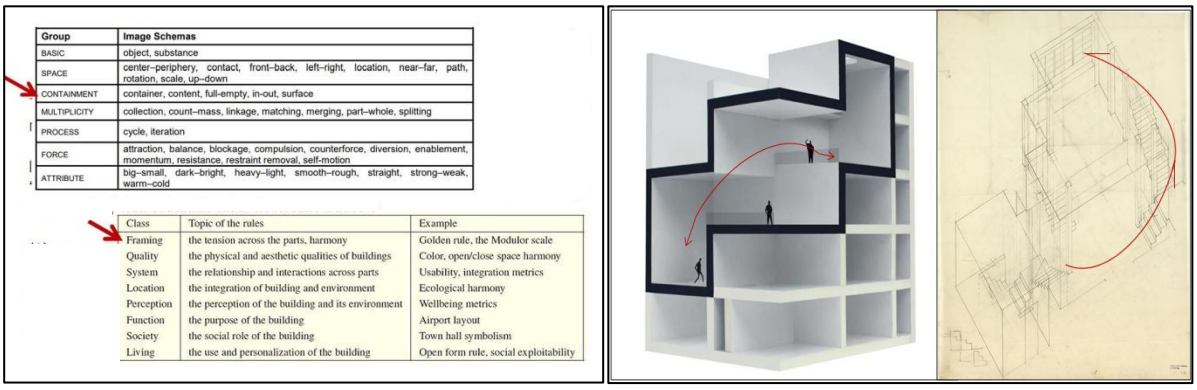
2. Ontological rules and image schema for creativity in architectural design

The design process unfolds within a framework of rules and constraints. Some of these are external, such as the type of structure to be created, the available technologies, and regulatory guidelines. Others are internal, shaped by the architect's experiences, memories, emotions, and creative imagination. At the heart of this approach is the body—the individual as both a perceiver and an actor within the space. From this perspective, architecture becomes centred on human experience, making the virtual simulation of movement and perception a fundamental part of the creative process.

As previously mentioned, we contributed to creativity in architecture by exploring the use of ontology and image schemas. The combination of these two approaches to modelling cognitive notions provides, in our view, the means to explain the architect’s creative process both at a mental level, as a game of rules, and at a practical level, as an exploration of the space-to-be. This framework for understanding architectural design involves viewing it as a discipline governed by rules and meta-rules, while also exploring metaphors as shifted patterns [3][4].

We explored the integration of these two approaches by analyzing the Raumplan by Adolf Loos as an architectural principle capable of transferring its internal ontological rules and the image schemas it refers to from one architectural object to another, even across decades. An excerpt of the analysis is provided in Figure 1 [2].

This perspective contrasts with traditional views of architecture, offering advantages such as enabling formal analysis and revealing parallels between architectural creativity and rule-based problem-solving in scientific domains. Moreover, image schemas, as described by [5], are abstract, recurring patterns derived from sensory and spatial experiences. These schemas are highly flexible, capable of structuring diverse perceptions, images, and events [6][7]. They embody knowledge and represent a form of "embodied imagination," shifting within the mind of the designing agent.



Group	Image Schemas
BASIC	object, substance
SPACE	center–periphery, contact, front–back, left–right, location, near–far, path, rotation, scale, up–down
CONTAINMENT	container, content, full-empty, in-out, surface
MULTIPLICITY	collection, count–mass, linkage, matching, merging, part–whole, splitting
PROCESS	cycle, iteration
FORCE	attraction, balance, blockage, compulsion, counterforce, diversion, enablement, momentum, resistance, restraint removal, self-motion
ATTRIBUTE	big–small, dark–bright, heavy–light, smooth–rough, straight, strong–weak, warm–cold

Class	Topic of the rules	Example
Framing	the tension across the parts, harmony	Golden rule, the Modulor scale
Quality	the physical and aesthetic qualities of buildings	Color, open/close space harmony
System	the relationship and interactions across parts	Usability, integration metrics
Location	the integration of building and environment	Ecological harmony
Perception	the perception of the building and its environment	Wellbeing metrics
Function	the purpose of the building	Airport layout
Society	the social role of the building	Town hall symbolism
Living	the use and personalization of the building	Open form rule, social exploitability

Figure 1: on the left an excerpt from the analysis of the Raumplan principle according to ontological rules and image-schema[2], on the right the parallelism between Casa Cala by Campo Baeza and Casa Moller by Loos with a graphic representation of the flow in the space from [17]

Operating at a level of abstraction beyond simple mental images, image schemas serve as a cognitive tool that links mental concepts with physical spatial and functional relationships. They are an essential component of human cognition and creative thinking, bridging the conceptual and performative aspects of design. By leveraging image schemas, architects can balance their creative vision with the practical requirements of their projects.

By exploring how image schemas and applied ontology can collectively contribute to an architect's mental visualization of a newly designed project space, we establish a connection between the mental and physical realms—one that the designer implicitly integrates as a unified experience during the creative process.

This perspective, as we have proposed, provides a pathway to harmonize architectural innovation with formal representation, fostering a collaborative space for human-machine co-creativity [2].

3. The joint research path about urban planning and applied ontologies

This research path initiated by applying the methodologies of applied ontology and ontological analysis into the managing and representation of memories (knowledge) during the creative phase of a design and expanding them to the planning processes for the territory and the city. The aim has been to gather and organize knowledge in planning processes in a clearer and disambiguated way.

An ontology, a conceptual artefact, offers a shared, precise vocabulary for experts and practitioners within a specific domain, enabling effective communication and information exchange. For this it is particularly effective in facilitating knowledge-sharing and resolving ambiguities, even across heterogeneous agents and human-machine interactions, helping to define the objects, attributes, relationships (including dynamic ones), and processes that form and animate a system.

In our research path along this exploration, *i.e.,* applying ontological analysis to planning processes, we elicited in a first step the ontological layers underlying the conceptualization of places. This led to identify three principal layers: the space level; the artifactual level; and the cognitive/social level, each of them populated by sub-levels [8], see figure 2.

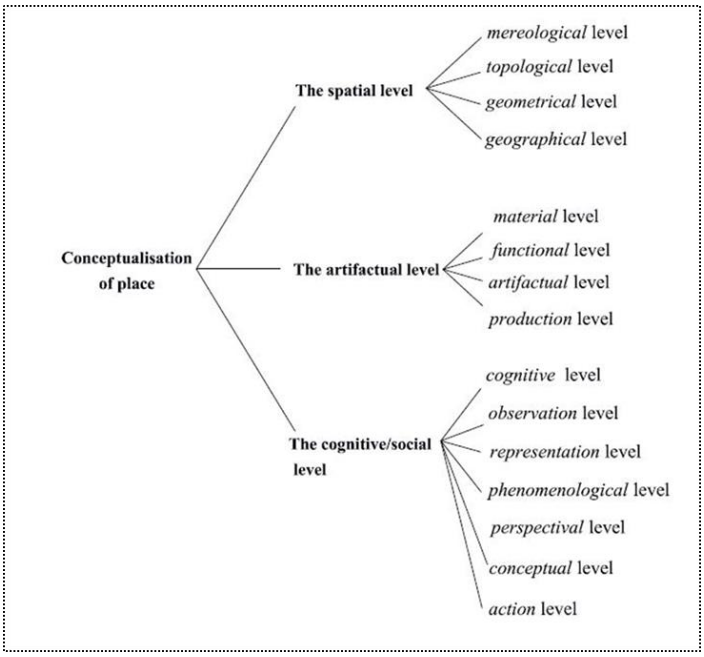


Figure 2: taxonomy of the conceptualization of place according to ontological levels as proposed in [8].

Regarding the second research line, we concentrated on the city as a complex, multi-dimensional entity characterized by the emergent properties of the system's elements. Following this view, we conducted an in-depth ontological analysis of cities, smart cities, and their components [9]. In this analysis, we identified three primary elements: (i) the physical dimension of place as distributed materiality, (ii) the community as a multi-layered agent with varying levels of agency, and (iii) knowledge as a comprehensive entity encompassing data, models, and meanings. We then added a fourth layer: the city relation, which explicates the substance of the exchange between the other parts, dynamically fixing the essence of the city [10]. These components interact in ways that are as vital as the components themselves—interactions are fundamental for the city's existence beyond the mere presence of these elements (Figure 3).

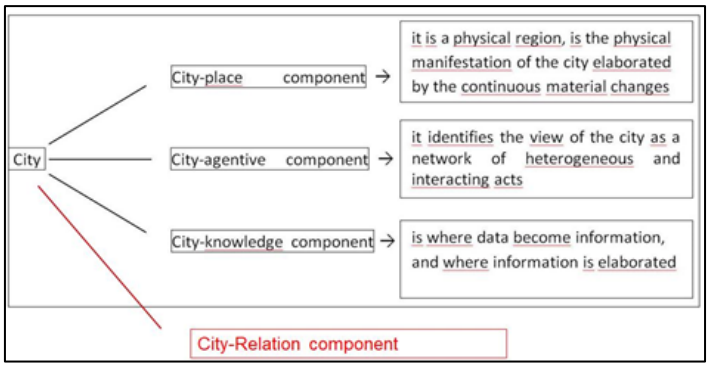


Figure 3: a graphitization of the ontological city layers with the fourth layer in [10]

This last effort is part of the exploration of opportunities and challenges related to digital twins (DT) of cities, where an interplay among three critical components—the physical city (place), its agency (community), and its knowledge (data and meanings) and relations—must be fully integrated. A comprehensive DT model should encapsulate the city as a whole. This is a significant challenge, so we hypothesized referring to a smaller, symbolic subsystem that could serve as an effective example [11]. Urban squares, for instance, are emblematic spaces that reflect the habits and social behaviors of city inhabitants. These spaces can be analyzed through their structural primitives (e.g., geometric shapes) and functional requirements (e.g., their intended purposes), offering an insightful microcosm for the larger urban system.

The goal here is to combine an ontology-based approach with the tools offered by image schemas to support the interpretation and representation of knowledge about the city in its entirety and complexity. This is the intuition we aim to develop.

As an example, we proposed in [10][11] the development of an ontology-based tool, a kind of digital twin specific to city modeling—an Onto-Urban-DigitalTwin. Our work there focused on the construction of an ontology-based model of a square, with the aim of studying how it could work, and then extended to the city. The model is intended to help manage and represent knowledge to support decision-making in planning by utilizing a shared, coherent, and transparent approach.

We believe that merging these two approaches could help nourish an effective Onto-Urban-DigitalTwin, and this research represents the first step in that direction.

As mentioned, image schemas, as semantic constructions arising from recurring perceptions, operate on a higher level of abstraction than mental images. Interestingly, it should be emphasized that they can be used to “structure infinitely many perceptions, images, and events” [6][7]. Image schemas connect mental and experienced spatial/functional relationships [5]. In the following section, we give a general description of an urban square.

4. Brief introduction to the urban square

Cities, and anthropized places in general, feed on and thrive through the life and awareness of those who inhabit them. Inhabitants shape their character through their cultural and social identification.

From this perspective, unlived places "embody" an error that is not merely a matter of planning but a conceptual and political strategy failure, where the choices made fail to foresee a creative approach to the life situations that will persist in the spaces they shape.

The square serves as a vital collective urban space and is a primary element in city formation. The urban system consists of both enclosed and open spaces, including public areas, private spaces, streets, and greenery.

These elements, both built (such as buildings) and empty (like streets, parks, and squares), are essential components of the urban fabric. We emphasize the significance of the square, which epitomizes an open public space with an important social role. Historically, a square has been defined as a public space with significant architectural and urban quality [12][13]. It serves as a center of convergence, or barycenter, for a specific urban area. The central square, or the system of squares that form the heart of a city, represents the centrality of public institutions, both civil and religious. It is often bordered by the city's main monuments, which embody the most important historical memories and serve various public functions.

In the context of the European urban landscape, the squares of Italy represent an episode of richness and complexity, a cultural model of great value. At the end of the 19th century, Camillo Sitte [12] developed his approach on civic and urban art by analyzing urban squares. He was the first to investigate the phenomenon of the square, its origins and transformations, its design challenges, usage values, and its role and meaning, all of which he explored in his famous book Der Städtebau (1889). The great lesson of the Viennese historian Sitte lies in his focus on the art of space, viewing squares (even the simplest) as masterpieces of urban art.

We have also explored knowledge about the city and squares through poetry and literature. The descriptions offered by the words of artists reach impalpable levels of perception that substantiate the experience of a place. We have also conducted an ontological analysis of this, aiming to integrate this knowledge with various types of data and information—such as sensor data, participation data, and so on.

Lynch (1960) [13] concluded that imaginary maps are constructed using five basic elements: Paths, Edges, Districts, Nodes, and Landmarks. These elements, which help people navigate and understand urban environments, form a framework through which individuals mentally map the city. In Olender [14], we find the application of image schemas in the process of space perception and way-finding systems, where the use of these cognitive patterns allows for a deeper understanding of how people

orient themselves and move through urban spaces. This work demonstrates how urban planning theories can be integrated with image schemas to better capture and represent the embodied experience of being and moving within the urban environment.

Here, we propose the idea of merging image schemas with applied ontology to achieve different levels of interpretation and to ontologically analyze the embodied knowledge that emerges from applying these schemas. In the following section, we will present a comparison of two very different squares, applying an image-schema-based analysis to illustrate this approach.

5. Piazza Navona and Djemaa el-Fna square

Scandurra [15] suggests that the modern city, in the imagination of our thoughts reflected on the city, is nothing more than one of the possible visions of the world. He compares two seemingly diametrically opposed places, Piazza Navona in Rome and the Djemaa el-Fna square in Marrakech, both destinations for thousands of visitors. He highlights the duality of the comparison by starting the description of these squares in the same way: people come from all over the world to know and admire them.

In Piazza Navona, there are representations, symbols, and architectures that demonstrate how man can create artificial landscapes comparable to the wonders of nature—a place that, even without human presence, does not diminish in its splendor. For Djemaa el-Fna square, the discussion is different: in a sense, he argues, the square does not exist without the people who inhabit it. It seems almost like a residual area, delimited "by large arteries and ugly architecture." The square is the people who occupy it, who animate it from early afternoon until late at night. Some reflections about the uses and the life of the square were initiated by Calafiore et al. [16], to which we connected in our work [10], where we began the first modeling steps for a square as a preliminary stage for the Onto-Urban-DigitalTwin of an urban square.

This open and interesting debate raises some questions: What is the real square? What are the characteristics that determine whether an area is a square? This comparison can be extended to many other squares in a broader comparative analysis, aiming to elicit, among other things, the core primitives of an urban square and the population of material objects, agents, knowledge, and relationships between the entities of each layer and across different layers.

In this contribution, we will focus on these two squares. Piazza Navona is one of the most famous squares in Rome, with its oval shape following the perimeter of the Stadium of Domitian, a former trace in the urban tissue that has evolved over centuries while maintaining its shape and substantial emptiness. In the center stands Bernini's Fountain of the Four Rivers, and there are two other fountains—the Fountain of the Moor and the Fountain of Neptune—at the ends. Halfway along one of the long sides, we can see the baroque façade of Sant'Agnese in Agone, where the architect Borromini contributed to the final composition, even though he did not start nor finish the work. The project was begun and completed by the Rainaldi father and son, commissioned by Pope Innocenzo X Pamphili.

Figure 4: some pictures about Piazza Navona: the monuments in the night, and one of the fountain by Bernini from: https://www.cntraveler.com/activities/rome/piazza-navona, https://www.viator.com/tours/Rome/Rome-by-night-with-pizza-and-gelato-included/d511-70968P44) the market and the Serliana in Palazzo Pamphili's façade, by one of the authors)

To represent an application of image schemas to Piazza Navona, we can describe it as follows, listing some image schemas that can be directly identified among others:

Center-Periphery: The Fountain of the Four Rivers at the center, and the surrounding space.
Container: The square as a space that contains people and activities but also serves as a boundary.
Balance: The symmetry of the fountains and buildings.

This image schema "picture" must then be integrated with the ontological conceptual levels and layers. Additionally, some ontology-based rules that define a square can be deduced from the square's analysis. In this case, primarily spatial relations come into play, as seen in the first step illustrated in Figure 5, which indicates the ontological level connected to the above-listed image schemas.

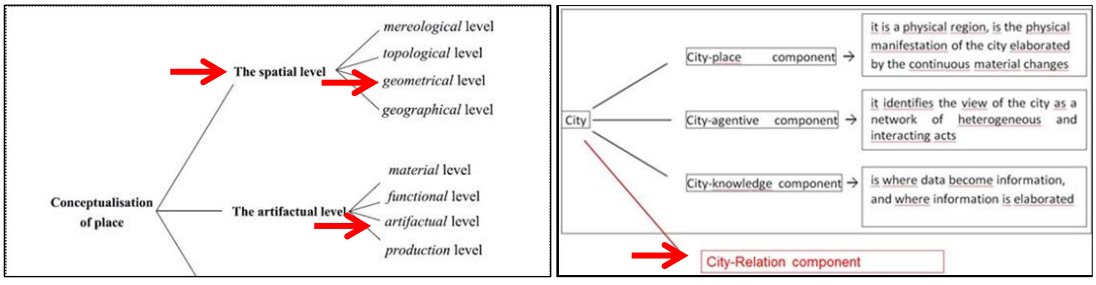


Figure 5: ontological layer and levels involved in the relation with elicited image schema.

Djemaa el-Fna Square, located in the heart of the medina of Marrakech, is a large, irregularly shaped square characterized by dynamic activity that shifts throughout the day. Morphologically, the square is a vast open space, surrounded by low buildings housing cafes, restaurants, and shops.

During the day, it functions as a bustling market where visitors can find spices, fabrics, jewelry, and traditional Moroccan crafts. As the sun sets, Djemaa el-Fna transforms into an open-air theatre, with food stalls, street performers, musicians, and storytellers contributing to an electrifying atmosphere.

Architecturally, the square is dominated by the presence of the Koutoubia Minaret, one of Marrakech's most iconic landmarks, located nearby. While the square itself does not contain monumental buildings, it is enriched by numerous stalls and temporary structures that are assembled and dismantled daily. This contributes to a dynamic and ever-evolving environment.

Figure 6: Djeema-el-fna some pictures in the day and in the night (https://www.istockphoto.com/it/immagine/africa-settentrionale)

An application of image schemas on Djemaa-el-Fna, gives the following result:

Center-Periphery: not well identified, the center is where people/activities are
Container: The square as a space that contains people, stalls and performances.
Balance: The balanced arrangement of stalls and activities around the square.
Verticality: The towers and structures that rise towards the sky, such as the Koutoubia.

In this case, the image schema "picture" does not remain confined solely to the spatial dimension. Even within a spatial interpretation, the agentive layer plays a crucial role in shaping the square, alongside the cognitive and social dimensions. The integration of ontological conceptual levels and layers brings particular emphasis to the relational and agentive layers.

While the image schemas presented and explained here may not be exhaustive, they represent an initial application of this cognitive-structural approach to urban modeling, providing a foundation for further exploration and refinement.

6. Conclusions

We find useful to investigate the mutual application of different research paths in order to provide a consistent framework for the modeling of complex environments like the urban territory. As presented in this contribution, we decided to develop a research approach that combines image

schemas with methods of ontological analysis and applied ontology in the planning process for cities and territories, specifically in the phases of analysis and knowledge gathering.

The ultimate objective is to manage and represent knowledge to support decision-making in urban planning. Among the various components of a city, the square stands out as a significant element characterized by intrinsic complexity, which justifies the chosen approach.

The use of image schemas can enhance our understanding of how agents perceive and move within urban spaces, adding a crucial cognitive dimension to the available knowledge.

References

[1] Bolisani, E., Borgo, S. and Oltramari, A. "Using knowledge as an object: Challenges and implications." *Knowledge Management Research & Practice* 10.3 (2012): 202-205.

[2] Stufano Melone, M. R., Borgo, S., & Kutz, O. (2022). Image Schemas and Ontology in Architectural Rules. In The Eighth Joint Ontology Workshops (JOWO'22), CEUR volume (Vol. 3249)

[3] Borgo, S., & Melone, M. R. S. (2018). How Architectural Rules Make Room for Creativity: An Ontology-Driven Analysis. In TriCoLore (C3GI/ISD/SCORE)

[4] Stufano Melone, M. R., Borgo, S., Ferrario, R., & Masolo, C. (2019). Towards a Framework to Store and Retrieve Memories for Creative Architectural Projects. In JOWO.

[5] Hedblom, M. M., Kutz, O., & Neuhaus, F. (2016). Image schemas in computational conceptual blending. Cognitive Systems Research, 39, 42-57.

[6] Hedblom, M. M., Neuhaus, F., & Mossakowski, T. (2024). The Diagrammatic Image Schema Language (DISL). Spatial Cognition & Computation, 1-38.

[7] Lakoff, G. (1987). Position paper on metaphor. In Theoretical Issues in Natural Language Processing 3.

[8] Stufano, R., Borri, D., Camarda, D., & Borgo, S. (2018). Knowledge of places: an ontological analysis of the social level in the city. Smart planning: Sustainability and mobility in the age of change, 3-14.

[9] Borgo, S., Borri, D., Camarda, D., & Stufano Melone, M. R. (2021). An ontological analysis of cities, smart cities and their components. Technology and the City: Towards a Philosophy of Urban Technologies, 365-387

[10] Stufano Melone, M. R., Borgo, S., & Camarda, D. (2024, July). City Interactions in UrbanPlanning: The Square Example from an Ontological Analysis Point of View. In International Conference on Computational Science and Its Applications (pp. 448-455). Cham: Springer Nature Switzerland

[11] Stufano Melone, M. R., Borgo, S., & Camarda, D. (2023, September). Digital Twins of Cities vs. Digital Twins for Cities. In International Conference on Innovation in Urban and Regional Planning (pp. 192-203). Cham: Springer Nature Switzerland

[12] Sitte, C., & Wieczorek, D. (1981). L'arte di costruire le città. L'urbanistica secondo i suoi fondamenti artistici (Vol. 65). Editoriale Jaca Book.

[13] Lynch, K. (1964). The image of the city. MIT press.

[14] Olender, K. (2022). Cities and Human Experience–the Touchpoints of Space Perception and Wayfinding Systems in the Communication Design Perspective. Loci Communes, 1-18.

[15] Scandurra, E. (2001). Gli storni e l'urbanista: progettare nella contemporaneità. Meltemi Editore srl.

[16] Calafiore, A., Boella, G., Borgo, S., & Guarino, N. (2017). Urban artefacts and their social roles: towards an ontology of social practices. In Leibniz International Proceedings in Informatics, LIPIcs (Vol. 86, pp. 1-13). Schloss Dagstuhl-Leibniz-Zentrum fur Informatik GmbH, Dagstuhl Publishing.

[17] A. Campo Baeza and D. Rincón de la Vega. Cala house. 2018.