FORMAL METHODS IN ARCHITECTURE AND URBANISM

VOLUME 2

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INTRODUCTION

CATARINA RUIVO, DAVID LEITE VIANA,
FRANKLIM MORAIS, AND JORGE VIEIRA VAZ

The International Symposium Formal Methods in Architecture is a biennial scientific meeting that has taken place in Portugal since 2011. The editors are members of their committees. Most of the papers of the 3rd edition of the Symposium (2015) were published in a book, *Formal Methods in Architecture and Urbanism*, by Cambridge Scholars Publishing.

This new volume includes a selection of papers presented to the 4th edition of the Symposium (2018). The editors would like to add a few preliminary words.

Formal Methods in Architecture

The main purpose of the symposia is a contribution to the debate about the application, in the disciplines of Architecture and Urbanism, of new formal methods—new methodological advances based on tools coming from Mathematics. From the millennial geometry to current shape grammars, several formal approaches to Architecture and Urbanism are presented, with their different points of view, different fields of application, and different grades of abstraction and formalization. The aim is to look at the potentials and purposes of these formal methods, both those on the horizon as well as those already accomplished, and both their successes and their problems. The intention is to promote the use of formal methods in the creation of new explicit languages for problem-solving in Architecture. These problems range from representation, to theory, critique, production, and communication, etc., never ceasing to see Architecture and Urbanism as technological activities as well as artistic ones.

The main fields of interest are the collection and low-level semantic organization of information (several methods of tracking and mapping—video; GPS, Wi-Fi; ISP; cellular phones; beacons; IoT-Internet of Things; GIS-Geographic Information Systems; BIM-Building Information Model/VDC-

Virtual Design and Construction); syntactically and semantically advanced formal languages (ontologies for the built environment; machine learning processes; shape grammars); formal theories (Space Syntax; SCAVA-Space Configuration, Accessibility and Visibility Analysis; cellular automata; agent-based design); project representation, visualization, and interaction (CAD-Computer Aided Design/BIM-Building Information Modelling; virtual reality; augmented reality; spatial augmented reality; human-computer interaction); low, medium, and high-level architectural design automation (CAD-Computer Aided Design/BIM/IFC-Industry Foundation Classes; parametric design; processing); advanced automated architectural design (shape grammars computer implementation; advanced reasoning artificial intelligence tools—heuristic and non-heuristic); building performance analysis (environmental analysis; multi-criteria analysis; flow and crowd analysis; biometric sensing of users); automated manufacturing—CAM (subtraction techniques; adding techniques; tessellation techniques); and the active management of the built environment (participatory urbanism; smart buildings; smart cities).

The more historically established areas for the application of mathematical sciences, such as traditional geometries or mathematical developments connected to engineering, are left somewhat outside our focus, without forgetting, however, the deep connections between them. Some of these new methodologies have a level of development that requires the existence of established academic communities, with their own specialized forums. Our symposia, which are more than an attempt to deepen each specific field (which are also), are above all about finding points of convergence. This is not limited to a possibly interesting abstract integration of different areas of research but it is mainly concerned with advancing the multiple crosses between various methods, whose fertility has already been proven.

A dialogue with semi-formal and even informal methods in current use has also been stimulated as a way to deepen the discussion on the controversies of aesthetics and ideologies that surround the possibilities and reach of a formalization of Architecture and Art. Even some contributions on the application of formal methods in fields other than architecture, like literature, music, and the fine arts, have been useful for architectural practice. These considerations could lead to the conclusion that the work is based on discussions of generalities and emptiness, which is not the case. A high level of technical depth is required on every single contribution. Formal rigor and acuity are constant demands for all participants.

The Structure of this Book

This volume aggregates about three dozen papers based on the Symposium presentations. The scope is the built environment, but a wide range of scales is presented, from the decorative tile to the room, from the house, from the building to the urban scale, from the street, and from the square to the city.

This volume is divided into two parts.

Part I includes the chapters that deal with the construction of the formal representations of the built environment. They start from the collection of relevant information, go through the semantic organization of that information with increasingly elaborate levels of semantic abstraction, and finally lead to theories, as well as structured and formal mental constructions about the built environment (the forms) and their relations with both the natural world and the psychic and social world of human beings (the functions). These theories, with a greater or lesser degree of complexity and abstraction, make it possible to carry out assessments on the desirability of architectural or urban solutions.

Part I has five sections:

Part I.1 encompasses texts that preferably use SCAVA-Space Configuration, Accessibility, and Visibility Analysis (e.g., Space Syntax, isovists, visual graph analysis, or agent-based analysis) methods and theories in urban problems. Most intend to establish the interrelations between the configuration of urban spaces and the human activities that develop in them, as both (forms and functions) interact and condition each other. However, these analyses are also concerned with the semantics within the language of the forms/spaces themselves for purely configurational and/or aesthetic evaluations, as is shown in Chapter 1.

Part I.2 groups texts that are still dedicated to urban analysis but which use other methods, especially GIS and its additional analysis and evaluation tools. The use of GIS and SCAVA methodologies together are also shared, as some of the texts in Part I.1 indicate. In Part I.2, texts with less formal methodologies are also presented. Chapter 10 is a good example of a more classic semi-formal analysis that can establish a good dialogue with formal methods. Although not completely formalized, some concepts from classical theories are relevant to a deep analysis of architectural practice and may be the object of the creation of future formalisms.

Part I.3 contains two texts with SCAVA methodologies applied to buildings, and Part I.4 does the same but in this case they are applied to landscape architecture.

Part I.5 contains two texts. One of them brings to our attention a very classic analysis of architectural theory, which contains many concepts that are also subject to formalization today. The other text makes a classic approach to a generic problem of urban studies but points out the subordinate lines in which it contemplates both more classic and more formal methods. Both texts serve to continue the discussion on the interaction dynamics between analysis and theory, either classical or formal, with the different forms that this interaction can take.

Part II deals with automatic design and project production methodologies. These formal methodologies for producing the built environment are much less developed than those related to the analysis of the built environment.

Part II.1 contains a single text, which is representative of part of the linguistic formalization effort. Any formal language needs very firm syntactic bases, so some studies have to be directed exclusively at the formal definition of very generic syntaxes and semantics. It is a work similar to that of mathematicians who provide languages for all sciences, although they are not tied to the practicality of their use.

Part II.2 brings us, mainly, generative languages that programmatically produce forms for environmental projects to be built in the future. Usually, many of these grammars contain exclusively syntactic production rules, so the forms generated are arbitrary and without any control from the point of view of their ability to interact with their exterior—the lives of human beings. Many of the chapters in Part II.2 overcome this problem. Those generative grammars use production rules that already take the knowledge that comes from the consolidated heuristics of architects into account. Grammars based on heuristic, cultural, aesthetic, and even social knowledge are presented. Some of the grammars are even built from the observation of reality and then used for future developments. Machine learning methods are used for this construction.

Part II.3 includes very interesting examples of the use of formal methods of production in an academic environment, with a view to training new architects to be sensitive to formal methods.

Part II.4 contains a single text that serves as an introduction to a dialogue with some trends of contemporary architecture which, although using semi-formal methodologies, are similar to formal tools.

4TH SYMPOSIUM FORMAL METHODS IN ARCHITECTURE: CLOSING REMARKS

FRANKLIM MORAIS

Honesty and Modesty

During the course of the Symposium's work, two of the presentations shook our minds. Not because the ideas and positions were so different from the rest, but because they reached two core points of an ethical behaviour.

In the first,[(1)] one of the authors presented a study where a set of theses were proposed to explain the influence of the permeability of facades on urban vitality. It was an application of Space Syntax methodologies to some observed behaviours in a Brazilian city. But this is not our topic. What we are trying to relive is that, at some point in the speech, the reader presented the conclusions, and said, “this and that thesis confirmed; this and that thesis not confirmed”. The three magic words were "thesis not confirmed". Many of us are used to a discourse on architecture where there is no research and no confrontation with reality. It only makes statements of principles, which are often ideological and/or normative. And yet there are those who first find the revealed truths and then the necessary *ad hoc* demonstrations to support them. Many proclaimed theses are clearly biased by ideological claims. It must be stressed that nothing moves us against ideology. There is no decision without some human appreciation and evaluation. The scientific commitment is only against the self-presentation of ideology as theory, and of norm as truth. The authors of this paper were clearly attached to some social, political, or cultural positions. Nevertheless, that did not prevent them from accepting partial defeat. They did not try to impose their wills on their results. They positioned themselves in the place of total honesty: the confrontation of their thesis with reality, through their theoretical method,

[(1)] “Development of a Permeability Measure Between Private and Public Space”, Patricia Alonso, Meta Berghauser Pont, and Luiz Amorim (Chapter 7).

corroborated some of them and those that were not confirmed had to be forsaken.

In the debate over another paper,(2) the author undervalued his own work, saying that it had not achieved a great level of conclusions. For some of us, who have been following his work for some time, this seemed somehow unfair. Actually, he has performed an overwhelming piece of work, with very detailed analysis on hundreds of squares, in order to obtain some conclusions on their configuration and behaviour. He had mathematically formalized several dozens of parameters, trying to get a formal definition and clustering of types of squares. At the end, the author was not that pleased. He just said that the work was not so good after all. But we could understand his modesty: despite all his work, he was still very far away from a semantically well founded "theory of the square". These same ethical positions globally and implicitly pervade all communications. Unlikely the traditional architectural papers, many of them used the current scientific template: they explicitly presented the underlying methodological base, they made experiments, their thesis was formally constructed, the results were discussed, and they usually presented the labour to be performed in the future to rectify the flaws of the present. We believe that the use of formal methodologies has a prominent role on these ethical (among others) achievements. Formalization implies making all the elements of the "speech act" completely explicit, implying not only the "speech" but also the process. Totally explicit knowledge needs the inclusion of the interpretative code to be used by other languages to make clear assumptions. The concepts of those structures are becoming increasingly diverse from those immediately tied to empirical perceptions of objects and those trying to search for essences of the reality far away from our senses. Nevertheless, their construction may be entirely mapped from the first assumptions to final results though all the algebraic movements of their construction. They can thereby be related to empirical data.

When someone presents a formal theory, they declare all the global assumptions (the code to interpret the theory, including the code for other people to understand the theory), all the terms, and all the rules of the generative grammar for creating new terms. Nothing can be hidden. One of the major tasks of a new theory is the explicit definition of its domain—the portion of reality it has to deal with. This means that each theory has a perfect understanding of what each theory is missing, which parts of reality

(2) "Linking Data Mining, Spatial Analysis and Algorithmic Design", João V. Lopes (not in this book).

it deliberately ignores, and its incompleteness. It never tries to be the answer to all problems. It knows that it is provisional and carries errors inside it, but it can also be improved in an endless process.

The Formalization of Art and Art Studies

I would like to stress a final topic: formalization (representing something in a formal language), which is not directed against Classic Studies. For example, in one other paper given at the Symposium,(3) the author brought us some old ideas in refreshed suits. The presentation focused on a semantic definition and organization of some now underrated concepts, such as grace, scale, decorum, order, and composition.

We might think we were moved in time and place to Quais Malaquais in Paris, in the late nineteenth century or the beginning of the following, where the lessons of the courses of Architecture brought us the Treatises of the Beaux Arts, from Guadet or, later, from Gromort and Gutton. For some, those treatises have already been thrown to the dustbin of History, aided by the numerous schools of "Arts and Crafts" and even more by the Vkhutemas and Bauhaus schools. This skirmish can be viewed from a broad perspective as an episode of the millennial conflict over rhetoric.

The position of Plato is well known: rhetoric is a good mean for the persuasion of the ignorant masses and not for the discovery of truth. Aristotle countered that it was good to study rhetoric because everyone could learn how he was deceived, but yet more relevant is the fact, forgotten by Plato, that even the mighty truth needs to materialize in some language to be revealed.

Modern speech act theory teaches us that sentences in natural speech are predominantly performative utterances. Semiotic studies do not say otherwise. So, even Plato's "Gorgias", where he painfully strikes rhetoric, is a rhetorical masterpiece. Even architectural modernism, whose discourse is quite far from rhetoric, could not avoid the use of architectural languages with their implicit rhetoric. Paraphrasing the mocking argument of someone

(3) "Form and Meaning in Architecture and Urbanism: Principles of Quality", Javier Poyatos Sebatián (Chapter 16).

(Robert Venturi), Beaux Arts has made monuments to something; modernism makes monuments to itself.

The Treatises of the Beaux Arts carried a great flaw: their linguist tropes were presented as perennial norms, giving them the very bad reputation of academism. But linguistic studies could split semantic concepts from their values and could reuse what was a real advance in conceptual systematization. Many of the old concepts are now formalised and are not tied to specific values. Looking further back, the old treatises did not suffer from the same flaws of academism. Maybe what we are really trying to do is to translate Alberti's concinnitas into a formal language.

–PART I–

REPRESENTATION OF THE BUILT ENVIRONMENT: FROM INFORMATION GATHERING TO THEORIES AND EVALUATION

I.1

SCAVA METHODOLOGIES IN URBAN STUDIES

CHAPTER ONE

ALEXANDER'S THEORIES APPLIED TO URBAN DESIGN[(1)]

ALICE RAUBER, ROMULO KRAFTA

Introduction

The relationship between urban design and science has always been highly debatable[1-4]. Using analytical methods in urban design has been a challenging question since they do not easily become part of the process.[5–6]. Despite the difficulties, several authors claim that urban design should be more evidence-based,[7–10] especially because of the increasing availability of data for cities and analytical tools, which opens up the possibility of a science of cities.[11, 12] In such a context, it is worthy to review some of the Christopher Alexander's theories. He is an architectural theorist pioneer in trying to find better ways to design. Since the 1960s, he has been outlining a theory of built space design that seeks to overcome the architectural/urban production as something conceived purely in arbitrary and subjective terms. Although he is best known by his seminal work *A Pattern* Language,[13] the focus here relies on the theories presented in *The Nature of Order,*[14] and related work.[15, 16] In his recent work,[14-16] Alexander has proposed very instigating theories about the harmony and beauty seen in natural and man-made artefacts, although his concepts remain very hard to grasp and unlikely to practical applications. Here we try to bring such concepts closer to a science-based urban design development. First, we briefly introduce the main theories.

Wholeness is the central concept in recent Alexander's work.[14-16] It can be defined as a global structural character of a given configuration existing in space, both in natural and man-made things. Alexander also calls it a living

[(1)] This chapter was previously published in the Special Issue "Formalizing Urban Methodologies". *Urban Sci*. 2018, 2(3), 86; https://doi.org/10.3390/urbansci2030086.

structure because it emerges from an incremental process. He argues that everything has some degree of life. Of course, he refers to non-biological sense. His meaning for life is more related to coherence and harmony.

Wholeness structure is composed of primary entities called centres. Those centres support and intensify each other through the repeated occurrence of fifteen geometric properties: levels of scale, strong centres, boundaries, alternating repetition, positive space, good shape, local symmetries, deep interlock and ambiguity, contrast, gradients, roughness, echoes, the void, simplicity and inner calm, and not-separateness. Such properties describe how the centres interact with each other. Properties help to increase the coherence and the strength of any given centre and to generate new ones. Alexander believes that the fifteen properties play a major role in making the wholeness of a system, because of the recurrence of them in all the coherent systems observed by him through many decades. Wholeness is, therefore, a recursively defined structure composed of centres, which in turn are composed of other centres. The successive application of transformations, in other words, computations, based on the fifteen properties lead to the formation of living structures. Such a process is harmony-seeking or wholeness-extending oriented[16] since it seeks to preserve the previous structure. However, it only happens when transformations are based on the fifteen properties.[16]

As we can note, the idea of wholeness addresses the underlying structure of systems, namely its hidden quality. The existence of sub-structures—the centres and the sub-centres—addresses a scaling hierarchy. Such understanding helps to bring design process closer to a complex sciences approach. According to Alexander,[15] scientists who study biology and physical phenomena, for example, are passive in regard to the aspect of creation. The architects, on the other hand, are key proponents, whose project errors interfere in the lives of many people so they should be aware of the design process. Therefore, the creation of complex structures—which is the case of architecture and urbanism—should become an important scientific topic. Alexander suggests that aesthetic plays a key role in the co-evolution of complex systems since the transformations that lead to the emergence of harmony and beauty in nature obey universal rules—the 15 properties. If it is true, such a process should be understood in order to be applied to the design process.

Finally, Alexander[14-16] argues that wholeness, namely the degree of life of a given configuration, is measurable since the properties can be objectively observed and described. However, the author himself admits that we still do not have a mathematical language or a computational method to achieve this. According to Alexander[14] (pp.364-367), although the measurement of wholeness relies necessarily on the human observer, it is not just a cognition problem, but something objective that exists in space. The author admits that we need a more objective and mathematical way to support the task of measuring wholeness in spite of his deep concern for human intuition, especially when analysing complex artefacts such as cities and building. He proposes a new research agenda to operationalise the harmony-seeking process[16]. Therefore, the main challenge would be to establish some way of describing and modelling the harmony-seeking process, the fifteen properties and the idea of wholeness. A reduced number of authors[17-20] have attempted to embark on the path outlined by Alexander. Salingaros[17] have suggested the first mathematical treatment for the degree of life. His measures are quite simple and present some limitation that indeed was highlighted by Alexander[14] (pp.469-472). Ekinoglu and Kubat[20] and Jiang[18, 19] have proposed interesting methods for measuring wholeness, the former based on entropy measure and the latter based on a complex network approach.

In line with Jiang's research, this paper discusses the possibilities and drawbacks of operationalising Alexander's concepts from a network analysis perspective. We argue that there are much more possibilities to explore towards a configurational approach than previously exposed by Jiang[18, 19]. We emphasise that a network approach is just one of the possible ways to explore Alexander's ideas. Obviously, there is a diversity of possible approaches, although in a reduced number of scientific papers, as we have just referred above.

The aim of this paper is contributing to the discussion of how to operationalise the harmony-seeking and centring process based on network analysis. This kind of research is important because it can lead to the development of a tool for assessing wholeness, in other words, a tool for supporting urban design decisions. Firstly, we attempt to bring Alexander's theories closer to an urban design context. Moreover, we attempt to bring it closer to an urban network perspective since we are concerned about configurational issues of urban design. Then, we highlight the diversity of spatial network analysis available in the field of urban configurational studies. It is illustrated with a case study, where we apply network-modelling methods. Finally, we discuss possibilities of increasing the potentialities of a network approach to operationalise Alexander's concepts. The paper concludes with the main drawbacks, challenging issues and possibilities for future research.

Bringing Alexander's Concepts to an Urban Design Context

Alexander's theories, as previously exposed, are too abstract and generic to be straightforwardly applicable to urban design processes, or any kind of design process at all. Consequently, some interpretation is required, especially if we are committed to operationalising measures. In order to make his concepts more concrete, we assume some delimitation.

The first one is to discuss wholeness and the properties within an urban design realm. In fact, urban design is still a broad field to deal with, since it covers a wide range of scales and aspects. Seen in these terms, urban design can embrace small details from streetscape, buildings typology, green areas and activities distribution, networks of infrastructures and even entire cities—to cite just a few examples. Fortunately, the broadness of Alexander's work is not limited to a single scale. However, dealing with such a wide range of scales would be impossible. Thus, the scale addressed in the present study is the whole city scale, in other words, the urban planning scale. Defining a scale make it easier to define what are the sub-components of the system, namely, the centres. If we are considering a city as the whole system, we can define the streets and built forms as the primary elements. Streets and buildings are precisely the key features in the structuring of urban morphology at this scale.

Several studies have shown that the configuration of the streets is a primary aspect in the structuring and dynamics of the cities, and it has been explored extensively through a network approach in the urban configurational studies[21-25]. Thus, the interconnectedness of the streets can be considered one of the most important aspects of the urban design in the scale we are addressing here. Similarly, the built forms can be considered as connected elements. Together with streets, buildings also contribute to give rise and to support the global character of the urban structure. Put it in other words, the built forms are as important as the street network, although studies attempting to include built forms are scarcer in the literature in the urban configurational literature[26-28].

The main aspect we focus on is the configuration of the core elements of the urban structure: street and built forms. We are concerned about how the spatial elements connect to each other, as typically approached in configurational studies. Thus, we assume an urban network approach, in which the streets and built elements play a major role. Graphs are the principal mathematical language to describe properties of connected components[29, 30]. Moreover, graph theory has been broadly used in urban studies[6, 21, 23-28, 31-35, 39-40]. This kind of work can be considered a particular field of urban morphology as it essentially addresses the configuration and the relationship between urban components. The main advantage is that the network properties of urban components can be mathematically manageable. In this sense, we argue here that this well-established research field can be useful to operationalise some of Alexander's abstract concepts. Besides, Alexander's recent theories are very suggestive of a network approach. According to Alexander, the degree of life of a given centre is defined not by the centre itself but by its position in the entire field of centres[14] (p.459). The author gives us others clues that make us believe that a network approach seems to capture the fundamental idea of wholeness and degree of life. Alexander suggests that each centre—as a bit of geometry in the space—affects and changes the other centres[14] (p.415).

Another bridge between Alexander's theories and a network approach is the scale-free property[19]. Some complex networks present far more less-connected elements than well-connected ones so that their degree of connectivity reveal a power law distribution. It is called a scale-free network[36]. Such property also has already been explored in urban studies[25, 32, 33, 35, 37]. The underlying structure and scaling hierarchy of artefacts are some of the key points in Alexander's theory, as previously exposed. In this sense, the network approach used in urban systems studies may be helpful to achieve it.

Finally, a network perspective on Alexander's wholeness has already been suggested[18,19]. Jiang defines wholeness as a hierarchical graph, in which centres are described as nodes and their relationships as links. The author suggests a mathematical model for wholeness, in which: a) PageRank score can measure the degree of life for each centre, and b) ht-index[38] can characterise the degree of wholeness for the whole system. PageRank (PR) score is an algorithm used to measure the centrality of websites. Jiang[18] applies it to measure the centrality of nodes in order to capture the hierarchy of the components. Ht-index is based on head/tails breaks, which is a clustering algorithm for data with heavy-tail distribution. It can be used for classification and visualisation of data, helping to characterise the levels of scale. Values are ranked in decreasing order and broken down by the average. Those above the average constitute the head and those below is the tail. This breaking process continues recursively for the head until the notion of far more small things is no longer present. Thus, ht-index can be defined as "the number of times that the scaling pattern of far more small things than large ones recur"[38] and can be used for comparing different systems.

The main problem in using PR is that it grasps only one characteristic of urban structure and it is not clear whether it is the best way to capture hierarchy. In fact, it is not clear if there is a better way to capture hierarchy since there are several different methods to measure urban centrality and obtain spatial differentiation. Besides, each centrality measure reveals different distribution patterns[33-35]. Therefore, many measures other than PR could be used to identify hierarchy in a graph.

In this paper, we assume that Jiang's suggestion is true and that network analysis can bring a suitable mathematical language for dealing with Alexander's insights. In the following sections, we discuss possibilities of improving such approach, considering the diversity of techniques in urban configurational studies unexplored to the task of measuring wholeness.

Urban Configurational Studies

Typically, urban configurational studies use discrete components to represent the urban system, so that each component correspond to nodes and their connection links in a graph. There are three types of criteria used to define the discrete components[39]: a) preservation of geographic features, b) maximum morphological units, and c) minimum morphological units. In Figure 01.1, we can see one example of each criterion: a) intersections, which preserves geographic features—distances between nodes; b) axial lines, as maximum morphological units; c) street segments, as minimum morphological units of streets network.

The first one "a" is useful when Euclidean distances are important, because the corresponding graph is equal to the map, as we can see in Figure 01.1. This kind of representation is also known as a primal approach[33, 34]. Both "b" and "c" are known as a dual approach[35] since the graph is different from the map. In this case, Euclidean distances are deformed.

Descriptive systems like "b" and "c" give priority to streets network. The main difference between them is the level of aggregation of components. Maximum morphological units, such as axial lines[21, 31] and continuity lines[40], are highly aggregated models because the primary units—the street segments—are merged according to a criterion, which is usually cognitive. Meanwhile, minimum morphological units can be viewed as a disaggregated form of axial representation[39]. Choosing the best descriptive system to model any problem is paramount because it strongly affects the results[33-35, 39]. In fact, one of the crucial points to operationalise Alexander' is how to represent the parts of a system. The parts, namely the centres, are the components of the urban graph. The examples in Figure 01.1 address essentially the street network. However, we know that other features should also be considered as primary entities, at least the built forms since they are key components of the urban design.

One of the core ideas to Alexander is that assembled centres compose wholeness structure. Thus, the recognition of the parts of the system is an important step to operationalise wholeness. The discrete components of graphs, as simplified representations of reality, already do this job. The descriptive system presented in Figure 01.1, commonly used in urban studies, can be considered as objective ways of recognising centres if we assume that each centre is a node in the graph.

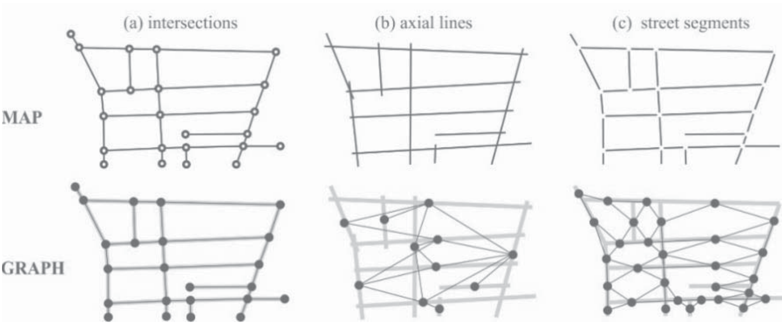

Figure 01.1

Three ways to represent the urban system as maps with discrete unites and their corresponding graphs.

Besides distinct descriptive systems, urban configurational studies have produced several graph-based methodologies to measure network properties of cities. We can group them into two types[39]: a) accessibility-based models, such as closeness centrality[33, 34, 41] and integration[21, 31]; and b) centrality-based models, such as choice[21, 31], betweenness centrality[33, 34, 42] and also the centrality measure developed by Krafta[28]. The first type is also known as distance-based measures and the second as relative position-based. Each measure gives us a different picture of the urban structure, showing spatial differentiation among centres. If we combine different measures with the different descriptive system showed above, we will have a set of distinct schemes to grasp spatial differentiation. In other words, we have a number of different ways of identifying the hierarchical relationship between the entities.

Material and Methods

In the present paper, we will not suggest new methods. Rather, we will illustrate how the distinct measures and descriptive systems often used in urban configurational studies can produce different results. Thus, the following case study aims at illustrating some of the models described before. Moreover, this case study helps to discuss the possibilities of using the resulting patterns as analogies for some of the properties. We argue that such understanding is crucial to the development of new methods to grasp Alexander's properties.

We model a real urban system, a medium-sized city in Brazil, which was chosen mainly because of its size. It is not too small nor too big. We divide the methodology into two steps. First, we explain the descriptive systems and the centrality measurement applied in this case, corresponding to the different manners to identify a hierarchical relationship in the urban system. Second, we suggest different manners to explore the results of the centrality scores from which we can identify possible connections with the geometric properties outlined by Alexander.

Descriptive Systems and Centrality Measures

The street network of the studied city is described in three different ways (Figure 01.2): intersections, street segments and axial lines. Each one has a corresponding graph, with a different number of units. We can consider each vertice of the graph as a centre. Then, we calculate three different centrality measures for each type of representation: closeness, betweenness and information centrality. These are classical centrality measures already used in urban studies[33, 34]. They were chosen because they are capable of grasping the global properties of a system.

In network analysis, the nodes are classified in a range of values according to the score that is being used. Therefore, with this set of measures, we have three different ways of identifying the hierarchical relationship between the nodes, namely the centres. Closeness measures "to which extent a node is near to all the other nodes along the shortest paths"[34]. Betweenness measures to which extent a node lies in the shortest paths connecting other couples of nodes[34]. Information measures the drop in the network efficiency when removing a node, therefore it can be related to the capability of the network to respond to the deactivation of nodes[34]. Mathematical formulation and deeper explanation of those metrics can be found in the literature[33, 34, 41, 42]. We perform the measures using Morphometrics[43], which is a software for urban network analysis developed by researchers from the Federal University of Rio Grande do Sul and the Federal University of Pelotas.

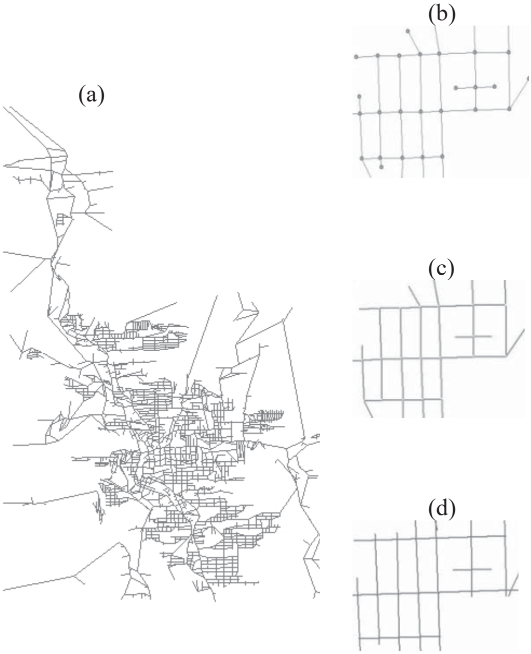

Figure 01.2

This picture shows (a) the city studied and a detail of the three descriptive systems used to represent the street network: (b) intersections, (c) street segments and (d) axial lines.

Exploration of the Centrality Measures Results

After performing the centrality measures, we have three different ways to characterise hierarchy among elements in three different descriptive system. Entities are ranked by values obtained through centrality models. In spite of that, the main question remains unaddressed. How can we measure the fifteen properties of Alexander—at least, some of them?

Jiang[18, 19, 38] uses the Ht-index to capture the levels of scale of a system. Whether it is a proper way of quantifying wholeness is arguable. However, it is certainly a good way to grasp the property levels of scale. It is at the same time an index and a visualisation scheme. And most importantly, it is done from the statistical distribution of the centrality metrics. Consequently, we claim that analysing the distribution of the results, spatially as well as statistically, is an important step of operationalising Alexander's ideas since the statistical distribution and the spatial patterns can enable us to identify some of the fifteen properties, other than levels of scale. Here we have explored the results of the centrality measures in two ways so that we could see how different measures and different descriptive systems affect them. The first one is the spatial distribution of the results, which enables a visual analysis. The spatial distribution of the centrality measures can be visualised through Geographical Information Systems (GIS). The second one is the statistical distribution of centrality measures, which is analysed by histograms built in RStudio.

Results

Spatial Distribution

We have standardised the visualisation in order to make it easier to compare the different descriptive systems. In spite of building the maps with different types of features, like lines or dots, we display all of them as graduated symbols. Hence, the larger features correspond to greater values, while the smaller ones correspond to lower values. Graduated symbols allow revealing the hierarchy of the values better than colour ranges, for most of the cases. The statistical method used to obtain the intervals is Natural Breaks.

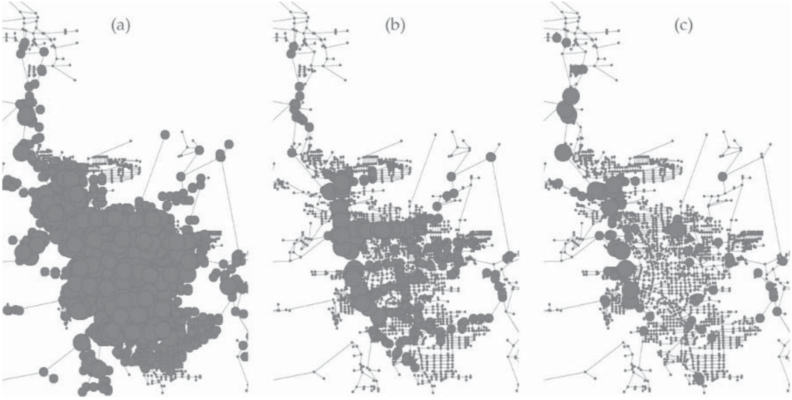

Figure 01.3

Spatial distribution of centralities for intersections/nodes (primal representation): a) Closeness Centrality; b) Betweenness Centrality; c) Information Centrality.

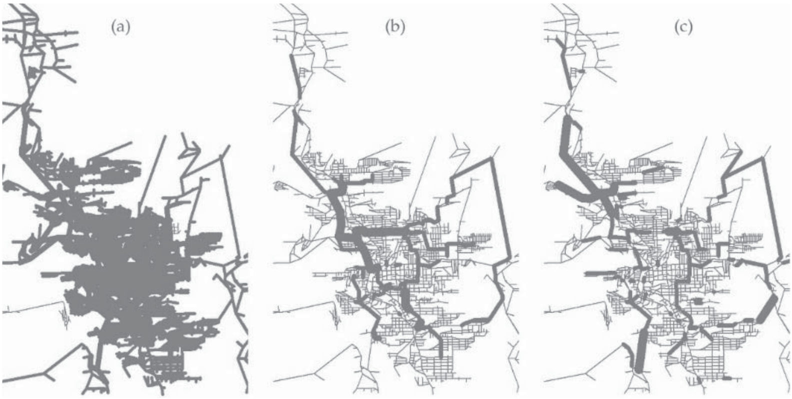

Figure 01.4

Spatial distribution of centralities for street segments (dual representation): a) Closeness Centrality; b) Betweenness Centrality; c) Information Centrality.

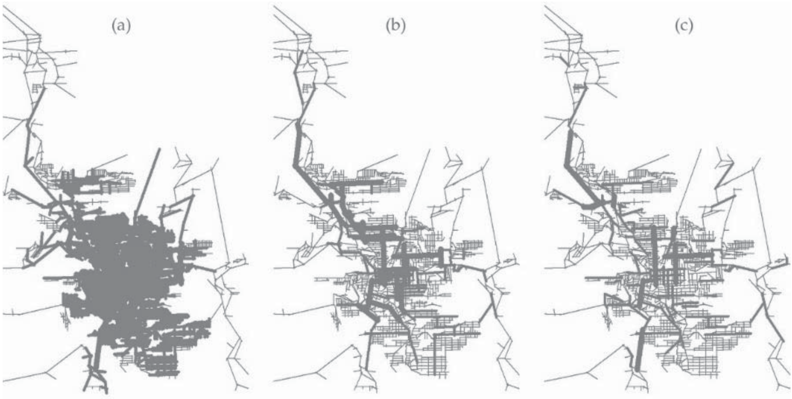

Figure 01.5

Spatial distribution of centralities for axial lines (dual representation): a) Closeness Centrality; b) Betweenness Centrality; c) Information Centrality.

As we can see in figures 01.3, 01.4 and 01.5, each measure has a different spatial pattern of distribution. Except for closeness centrality, the others present distinct patterns of distribution depending on the descriptive system.

Statistical Distribution

The histograms (Figure 01.6) show the statistical distribution patterns of the centrality measures. Betweenness and information centrality are more likely to have a heavy tail distribution, while closeness centrality is more likely to have a normal distribution, no matter the descriptive system. The characteristic distribution of the values of betweenness and information centrality suggests exponential or power law distribution. However, using simply a histogram to verify power law histogram is a very poor way proceed to verify a scale-free distribution. Of course, it must be confirmed by more powerful statistical packages in future investigation.

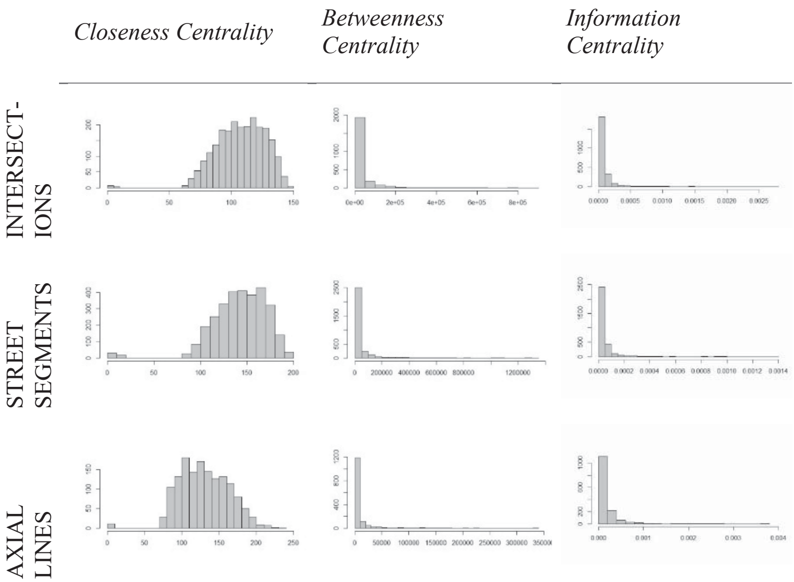

Figure 01.6

Histograms showing the statistical distribution of centralities measures.

Centrality Patterns vs. *Alexander's Geometric Properties*

Here we attempt to recognise analogies between the resulting patterns from centrality metrics and some of the Alexander's properties. First, the visualisation of the spatial distribution of the results for each centre allows us to recognise strong centres, one of the fifteen properties; although it changes accordingly to the metric which is being used and also to the descriptive system. The 10 or 20% of the highest values for each measure could be considered as being the strong centres. Second, we can see the gradient property since we have different classes of values, represented by features of different sizes. As we can see, closeness centrality is not good to grasp it, since it has not a strong distinguishing power. By contrast, betweenness and information centrality seems to be promising measures. As closeness centrality has not a strong distinguishing power, the better visualisation scheme is a colour ramp. In Figure 01.6, we use a colour ramp in which results are grouped into six classes. This way we can distinguish gradients for this centrality measure. Consequently, we adopt the quantile method rather than Natural Breaks, which is better for normal distribution samples. Regarding the visual pattern of distribution, in this type of measure, the highest values tend to converge for the geographic centre of the system since it is distance-based.

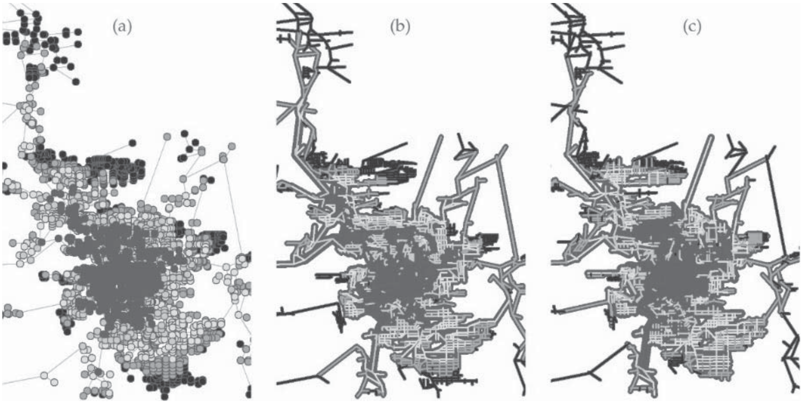

Figure 01.7

Closeness Centrality in three different descriptive system: a) Intersections; b) Street Segments; c) Axial Lines.

As regards to statistical distribution, we can see that distance-based measures, such as closeness centrality, are more likely to have a normal distribution. Measures based on the relative position of vertices, such as betweenness and information centrality, are more likely to have heavy tail distribution. It means that they have stronger differentiation power, which is a good way to identify hierarchical levels in a given configuration. Thus, they can be related to levels of scale, being an alternative to PR centrality suggested by Jiang[18, 19].

Discussion

In this section, we discuss how to improve the network approach already suggested in the literature. Each of the centrality measure combined with different descriptive system reveals distinct spatial and statistical distribution. As we could realise with this case study, closeness, betweenness and information centrality seem to have potential to be used as methods for operationalising Alexander's concepts, since they can be related to some of the geometric properties, especially if we look at the spatial and statistical distribution of the results. Of course, it needs to be more developed.

Adopting an approach similar to Jiang[18, 19], within a network perspective, instead of using only PR centrality[18], we can use a set of different centrality measures, or to choose the measures that best fits the design objectives being carried out. For instance, information centrality[33, 34] can show the vulnerability of the system, while, closeness and betweenness can show potential to retail activities[21, 31]. Fortunately, there are many pieces of evidence in the literature about the relationship between centrality measures and aspects of real life.

Alexander's theories are too abstract to be applied straightforwardly to urban design. However, the visualisation of the resulting patterns obtained through the centrality measures can be connected to some of the fifteen geometric properties. In this sense, a network approach can be seen as a bridge between Alexander's concepts and practical application to urban design. In the future, it can be explored as a monitoring tool. Such a tool can be thought of as a supporting tool for urban designers, as well as a monitoring tool for the city growth. Of course, we still need a lot of research to have a better understanding of the potential of the fifteen properties and wholeness to indicate quality of the built environment. We are aware that some of Alexander's core ideas remain unaddressed. Thus, we highlight some of them, for future research. The first one relates to the approach used to build the urban graph and the components considered as centres. The three methods showed in the current paper deal mainly with the street network. However, it is a poor approach, since urban design deals with many other crucial aspects, such as built forms and activities. Thus, we need to find out how to incorporate them in the urban graph, overcoming the strict street network view, commonly used in urban configurational studies. The next step of this research is to study more detailed descriptive systems, which include the built forms, for example. There is another worrying issue regarding the urban graph. Some of the descriptive methods tested in this paper are regular networks, which means that they have a uniform degree of connectivity. However, the best way to grasp wholeness and scaling hierarchy is using a complex network perspective, as suggested by Jiang[12, 13]. Regarding this issue, axial lines seem to have some advantage. Nevertheless, a small-world network could also be achieved by incorporating built forms as components of the graph.

Finally, another issue that remains unaddressed is the notion of the properties as transformations, namely being part of a harmony-seeking process. We could gain more insights if we consider centrality as a process rather than static measures. It could be done by running the centrality measures at various time snapshots. Such procedure could be used as a tool for monitoring design process and the urban development of a city.

Conclusions

This article took a network approach to Alexander´s findings. The focus was to bring Alexander's abstract theories into the urban design realm, specifically addressing configurational issues. Since the aim was contributing to the operationalisation of Alexander's concepts through a network perspective, we attempt to discuss how to improve the network approach already suggested in the literature.

The approach adopted enhances the idea that we can address the notions of wholeness and centres from a network perspective, as previously suggested[18, 19]. Nevertheless, we observe that a more careful selection of descriptive systems and measuring methods should be done considering the variety of methods available. In this paper, we attempt to identify existing network techniques that seen to be suitable for the task established by Alexander, beyond Jiang's suggestion. A key point to move forward is a deeper investigation on how to describe the urban elements, how to build the graph, how to identify spatial differentiation and how to visualise the results. Therefore, the current paper provided some clues for further studies on the challenging task of operationalising Alexander's from a network perspective. It could be supported by spatial network analysis techniques, GIS, and statistical packages. This kind of research is important because it can lead to the development of a new tool for supporting urban planning and design. However, we depend on more research addressing network properties to urban behaviour to produce a useful tool derived from Alexander's theories.

References

1. Cuthbert, A R (2007) 'Urban design: requiem for an era—review and critique of the last 50 years'. *Urban Design International*, 12(4), pp.177-223, doi:10.1057/palgrave.udi.9000200.
2. Marshall, S (2012) 'Science, pseudo-science and urban design'. *Urban Design International*, 17(4), pp.257-271, doi:10.1057/udi.2012.22.
3. Dovey, K, Pafka, E (2016) 'The science of urban design?' *Urban Design International*, 21(1), pp.1-10, doi:10.1057/udi.2015.28.
4. Salingaros, N (2005) *Principles of urban structure*. Amsterdam: Techne Press. ISBN 90-8594-001-X.

5. Çalişkan, O, Marshall, S (2011) 'Urban morphology and design: Introduction', *Built Environment*, 37(4), pp.381-392, doi:10.2148/benv.37.4.381.
6. Karimi, K (2012) 'A configurational approach to analytical urban design: space syntax methodology'. *Urban Design International*, 17(4), pp.297-318, doi:10.1057/udi.2012.19.
7. Timmermans, H (ed) (1993) *Design and decision support systems in architecture*. Kluwer Academic Publisher: Dordrecht, Netherlands. ISBN 0-7923-2444-7.
8. Klaasen, T (2003) 'Knowledge-based design: developing urban & regional design into a science', PhD thesis, Technische Universiteit Delft.
9. Karimi, K (2012) 'Special Issue: Evidence-informed and analytical methods in urban design' [Editorial]. *Urban Design International*, 17(4), pp. 253-256, doi:10.1057/udi.2012.24.
10. Batty, M (2013) 'Defining geodesign (= GIS + design ?)' [Editorial]. *Environment and Planning B*: *Planning and Design*, 40, pp.1-2, doi:10.1068/b4001ed.
11. Batty, M (2013) *The new science of cities*. MIT Press: Cambridge. ISBN 9780262534567.
12. Bettencourt, L, West, G (2010) 'A unified theory of urban living'. *Nature*, 467, pp.912-913, doi:10.1038/467912a.
13. Alexander, C, Ishikawa, S, Silverstein, M, Jacobson, M, Fiksdahl-King, I, Angel, S (1977) *A pattern language*. Oxford University Press: New York, USA, p.1171, ISBN: 9780195019193.
14. Alexander, C (2002) *The nature of order: an essay on the art of building and the nature of the universe*, Book 1. The Centre for Environmental Structure: Berkeley, USA.
15. Alexander, C (2003) *New concepts in complexity theory arising from studies in the field of architecture: a response by Christopher Alexander*. Katarxis, 3, pp.1-24.
16. Alexander, C (2009) *Harmony-seeking computations: a science of non-classical dynamics based on the progressive evolution of the larger whole*. International Journal for Unconventional Computing, 5.
17. Salingaros, N (1997) *Life and complexity in architecture from a thermodynamic analogy*. Physics Essays, 10, pp.165-173.
18. Jiang, B (2015) 'Wholeness as a hierarchical graph to capture the nature of space'. *International Journal of Geographical Information Science*, 29(9), pp.1632-1648.
19. Jiang, B (2016) *A complex-network perspective on Alexander's*

Wholeness. arXiv:1602.08939 2016, pp.1-12, doi:10.1016/j.physa.2016.07.038.
20. Ekinoglu, H, Kubat, A (2017) ‘Measuring and visualization of spatial change using information entropy’. In *Proceedings of the 11th International Space Syntax Symposium*, Instituto Superior Técnico: Lisbon, Portugal, 58, pp.1-15, ISBN 978-972-98994-4-7.
21. Hillier, B (1996) *Space is the machine*: *a configurational theory of architecture*. Cambridge University: Cambridge, London, p. 463. ISBN 1511697768.
22. Salat, S, Bourdic, L, Labbe, F (2014) ‘Breaking symmetries and emerging scaling urban structures: a morphologic tale of three cities Paris, New York, Barcelona’. *International Journal of Architectural Research*, 8 (2), pp.77-93.
23. Strano, E, Nicosia, V, Latora, V, Porta, S, Barthélemy, M (2012) ‘Elementary processes governing the evolution of road networks’. *Scientific Reports*, 2, 296, doi:10.1038/srep00296.
24. Shpuza, E (2014) ‘Allometry in the syntax of street networks: evolution of Adriatic and Ionian coastal cities 1800-2010’. *Environment and Planning B*: *Planning and Design*, 41, pp.450-471, doi:10.1068/b39109.
25. Nilsson, L, Gil, J (2017) ‘Finding the secret formula: how can we quantitatively understand cities’ growth, based on their street network structure?’ In *Proceedings of the 11th International Space Syntax Symposium.* Instituto Superior Técnico: Lisbon, Portugal, 58; pp.1-15, ISBN 978-972-98994-4-7.
26. Krüger, M (1979) ‘An approach to built-form connectivity at an urban scale: system description and its representation’. *Environment and Planning B*: *Planning & Design*, 6(1), pp.67-88.
27. Krüger, M (1980) ‘An approach to built-form connectivity at an urban scale: relationships between built-form connectivity, adjacency measures, and urban spatial structure’. *Environment and Planning B*: *Planning & Design*, 7(2), pp.163-194.
28. Krafta, R (1994) ‘Modelling intraurban configurational development’. *Environment and Planning B*: *Planning and Design*, 21(1), pp.67-82.
29. Newman, M, Barabasi, A, Watts, D (2006) *The structure and dynamics of networks*. Princeton University Press: New Jersey, USA. ISBN 9780691113562.

30. Barthelemy, M (2011) ‘Spatial networks’. *Physics Reports*, 499, pp.1-101, doi:10.1016/j.physrep.

31. Hillier, B, Hanson, J (1984) *The social logic of space*. Cambridge University Press, Cambridge, London. 1984; ISBN 0521367840.
32. Buhl, J, Gautrais, J, Reeves, N, Solé, R, Valverde, S, Kuntz, P, Theraulaz, G (2006) 'Topological patterns in street networks of self-organized urban settlements'. *European Physical Journal B*, 49(4), pp.513-522. doi:10.1140/epjb/e2006-00085-1.
33. Crucitti, P, Latora, V, Porta, S (2006) 'Centrality measures in spatial networks of urban streets'. *Physical Review E*, 73(3), pp.1-4. doi:10.1103/PhysRevE.73.036125.
34. Porta, S, Crucitti, P, Latora, V (2006) 'The network analysis of urban streets: a primal approach'. *Environment and Planning B*: *Urban Analytics and City Science*, 33(5), pp.705-725. doi:10.1068/b32045.
35. Porta, S, Crucitti, P, Latora, V (2006) 'The network analysis of urban streets: a dual approach'. Physica A: *Statistical and Theoretical Physics*, 369(2), pp.853-866. doi:10.1016/j.physa.2005.12.063.
36. Barabási A, Albert, R (1999) 'Emergence of scaling in random networks'. *Science*, 286, pp-509-512.
37. Jiang, B (2006) 'Small world modelling for complex geographic environments'. In Portugali, J *Complex artificial environments*: *simulation, cognition and VR in the study and planning of cities*. Springer: Heidelberg, Germany, pp.259-271.
38. Jiang, B, Yin, J (2014) 'Ht-index for quantifying the fractal or scaling structure of geographic features'. *Proceedings of the Association of American Geographers*, 104(3), pp.530-541.
39. Faria, A P (2010) *Análise configuracional da forma urbana e sua estrutura cognitiva*, PhD thesis, Federal University of Rio Grande do Sul, Porto Alegre, Brasil.
40. Figueiredo, L, Amorin, L (2005) 'Continuity lines in the axial system'. In *Proceedings 5th International Space Syntax Symposium*, Delft, Netherlands, pp.161-174.
41. Freeman, L (1979) 'Centrality in social networks conceptual clarification'. *Social Networks*, 1, pp.215-239.
42. Freeman, L (1977) 'A set of measures of centrality based on betweenness'. *Sociometry*, 40, pp.35-41.

CHAPTER TWO

MEASURING URBAN RENEWAL: A DUAL KERNEL DENSITY ESTIMATION TO ASSESS THE INTENSITY OF BUILDING RENOVATION[(1)]

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RICARDO MENDES CORREIA,
ALEXANDRA PAIO

Introduction

Building renovation has gained increasing relevance in the Portuguese context (Graph 02.1), particularly in its two major cities, Porto and Lisbon, in a context of decreasing activity of the building construction sector.[1] This urban renewal process appears to be concentrated on historic city centres, mainly of Porto and Lisbon, and their 19th century and early 20th century expansions. It differs from traditional top-down urban renewal processes in the sense that there has been no public or privately led large scale expropriation or demolitions to give way to redevelopments. Instead, it is composed of a large number of small interventions in existing structures that maintain the existing plot morphology. These interventions mostly comprise of the following: (1) additions to the original building volume, (2) alterations to the plan typology or spatial distribution, and small subsets of (3) façade refurbishment or maintenance and (4) reconstruction. Consequently, it is mostly a bottom-up privately led urban renewal process whose spatially asymmetric and local nature eludes traditional city level statistical tools. Yet, it would be useful for all city stakeholders, particularly

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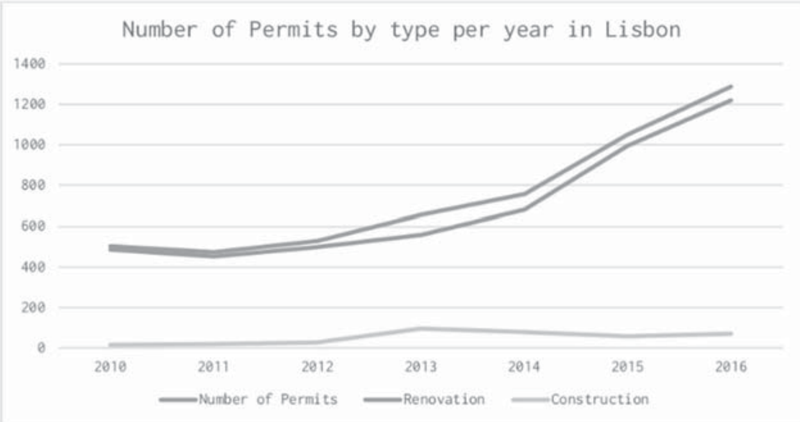
[(1)] This chapter was previously published in the Special Issue "Formalizing Urban Methodologies". *Urban Sci*. 2018, 2(3), 91; https://doi.org/10.3390/urbansci2030091.

to city planning officials, architects, or real estate agents, to assess the local intensity of these processes, preferably at the neighbourhood scale.



Graph 02.1

Number of Permits per type per year in Lisbon.

Understanding urban complexity and describing it are related and complex issues. An urban planner/designer must first produce a synthesis of the city to plan/design over that synthesis. An important step towards that kind of approach was taken by Kevin Lynch,[2] with the creation of a synthesis of spatial relationships in the city through mental maps. Those mental maps are a group of five elements: (1) *paths*, (2) *edges*, (3) *districts*, (4) *nodes,* and (5) *landmarks*. That concept, combined with the Alexander's hierarchical systems[3] or Gehl's[4] idea of complexity of the urban space between buildings, evolved to what Salingaros calls the "theory of urban web"[5] or to Michael Batty's Complexity Theory in Cities and Planning.[6] Batty is also protagonist of important research in modelling the city complexity[7]. Providing better ways of modelling urban phenomena at the onset of a planning process or a project is important, it is when that information can be more helpful for architects and urban planners. Models or statistical methods can assist in obtaining insights over future changes in an area of interest for a project or a plan.

Using computational tools, it is possible to generate maps that correlate city hall databases of building permit applications with georeferenced data. In previous work,[8],using Lisbon and Toronto's City Hall databases of planning applications, between 2010 and 2016, and georeferenced vector information we focused on generating maps that lend themselves to analytical study, developing a process of georeferencing building permit application processing times. While these maps are useful at a neighbourhood level, at the city scale they become harder to visualise. Also, they represent the occurrence of renovation, but do not compare it with the underlying density of the urban morphology. Additionally, city hall building permit databases do not account for all renovation work, because some renovations are exempt, and others proceed illegally.

Statistical methods, such as Kernel Density Estimation (KDE),[9, 10] have the capacity to overcome incomplete data, providing estimations on the continuous density of the observed phenomenon. Its use is adequate in informal investigation of the properties of datasets, providing information about skewness and multimodality.[11] Other advantages of these methods are the capacity to provide readability at the city scale. Multivariate KDE has been widely used to estimate the distribution of diverse events over bi-dimensional space, such as disease across a country,[12] to examine associations between neighbourhood destination intensity, walking and physical activity[13] or to study the urban sprawl in China.[14] With the implementation of open data policies by city halls across major European and American cites, this method is a convenient approach to investigate the properties and determine their distribution on a large volume of data.[15, 16] It is also useful in presenting analysis of complex data.[11] This paper presents preliminary research on the application of KDE to determine the intensity of building renovation on the city of Lisbon. Intensity, in this context, is understood as the proportion of renovated buildings over the total number of existing buildings in an area. To estimate intensity a Dual KDE is tested. A GIS software is used to produce reference intensity estimations using a KDE plugin. The methodology is transposed to a parametric modelling environment, which is more familiar amongst architects, and the results are compared. The limitations of the Dual KDE are then discussed and alternatives for improving the accuracy of the estimates are proposed.

Methodology

Building Renovation

The databases used in this work were provided by the Lisbon City Hall. It is composed of georeferenced vector information, in shapefile format, and a database with application admission, approval and issuing dates of building permits; administrative proceeding and building permit types; a building unique ID; and a building type amongst other types of administrative specific information. The building permit type is the key information that distinguishes permit applications for new buildings from renovation permits. Overall, there are twelve categories that can be divided into three groups: Construction, Renovation and Others. The Renovation group contains four categories: Alteration, Expansion or Addition, Reconstruction, and Conservation.

The Construction group only contains new building permits, and the Others group is comprised of administrative procedures without urbanistic relevance, that make changes to ongoing permits or that cannot be included in the previous groups. In this study, only the Renovation group is considered, and all its subcategories are joined into one set.

An Alteration is a change to the existing building maintaining its volume, but not either its structure, stairs, facades or infrastructure. All other types of interior refurbishment, like changing the dimensions of compartments, aren't required to submit for a building permit. An expansion or addition is a change of the building's original volume and/or plan, and a Reconstruction is demolishing the existing structure, maintaining or not the existing façade, and rebuilding it within the same volume and plan. On the other hand, Conservation works are those required to return the structure's exterior envelope to its original condition. An important limitation of this database is that while it includes all the new construction activity in the city, the same is not true for Renovation. Two reasons concur to this fact.

First, renovations of interior layouts, that do not change the building structure or infrastructure, are not required to submit for building permit. This exemption excludes all interior conservation and refurbishment work from the city hall database.

Second, the ambiguous nature of this definition provides leeway to an unknown number of renovation work, which would otherwise have to apply for a building permit, to proceed without doing so. Consequently, the city hall database is a sample of all building renovation that effectively happens in the city, since it does not include one of its subsets, it is incomplete on the alterations, while it likely includes all reconstructions. Yet, as a working hypothesis, we assume this dataset to be an unbiased sample of the real renovation work. The reasons are that building renovation is deeply influenced by location and building age. While it is outside the scope of this article to demonstrate these assumptions, tourism and foreign investment are widely identified as the main drivers of the current urban renewal phenomenon. These two drivers coincide in seeking central locations, which is precisely where the buildings are older in our case study.

Kernel Density Estimation

Kernel Density Estimation (KDE) is a method of estimating the smooth probability density function of discontinuous spatially distributed underlying data. Compared to other methods, such as histograms or naïve estimators, the estimation it produces is not influenced by the choice of an origin and a direction of the analysis grid. This is particularly useful in urban contexts, as it is not necessary to impose arbitrary grids that would inevitably involve compromises and eventually obscure patterns in the data. In two-dimensional analysis, as in our case, it produces a three-dimensional surface that is smooth and continuous, improving its readability and making it easier to generate contour diagrams. Furthermore, it is a widely available method in GIS software. The required inputs are the points where the events are located, a choice of type of kernel function, a window or bandwidth, and the definition of the analysis mesh. Since we are dealing with buildings, any point that falls within or on the boundaries of the building's polygon could be considered. We choose to use the centroid of the polygon, as this point can be retrieved accurately for all buildings both in GIS and the parametric environment. There are several options for Kernel functions, being the most common the Gaussian or normal kernel and the Epanechnikov quadratic kernel. We selected the latter[11] because it is less computationally expensive and it evaluates to zero if the distance of the event is larger than the window. This means that it is a more local measure than the normal kernel. For the same reasons, we selected a window of 400m as proposed by King[13] for walkability studies.

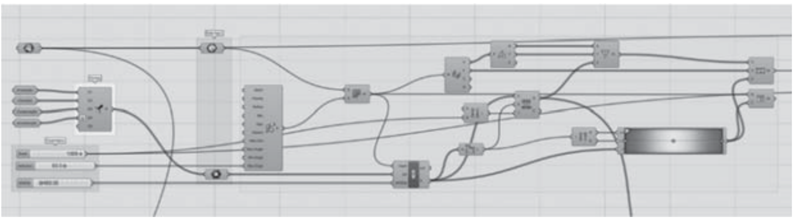


Figure 02.1

Visual programming script for generating a KDE from input points and a surface.

We adapted the methodology to parametric modelling environment in the following way (Figure 02.1). First, a mesh that encompasses the council border is generated, the mesh subdivision determines the definition of the resulting KDE, we used maximum size of 50m. Then a Kernel function, in our case the Epanechnikov quadratic function with the corresponding computational optimizations proposed by Silverman,[11] is applied to every event point in the city (renovation occurrences or existing buildings in the city). Finally, for each vertex in the mesh a kernel density estimation is assigned. This estimation is the result of the sum of the evaluation of the kernel function multiplied by the inverse of the number of existing points (i.e., all the renovation occurrences) times the kernel window squared. The inversely proportional nature of KDE with regard to distance means that the longer the points are apart the smaller is the estimate. A high concentration of points results in high KDE values. For viewing purposes, the last steps are scaling the surface Z coordinates, colouring the mesh and producing contours every 10%. Nevertheless, one of the limitations of the application of KDE in urban spaces is that buildings are not uniformly distributed, that is, the city has an underlying density. Furthermore, building renovation can only occur in existing buildings. To overcome this limitation, Dual KDE has been used[12] to compare the density of the observed events with the density of the finite set in which these occur. In our case, the events are building renovation and the finite set is all the existing buildings in the city. This is achieved by dividing the KDE of building renovation by the KDE of all buildings in the city. The resulting surface is the intensity of building renovation in the existing urban form.

Results

The Lisbon City Hall cartographic base has a unique GIS ID (codigo SIG) for each building used across the shapefile and the alphanumeric building permits database. All buildings in the city, whether public or privately owned, are referenced. This allows cross-referencing the information distributed amongst several databases and map or reference many of the city hall activities, such as social services rented council houses, lots to be sold by the city hall, planning permits, building permits, etc.

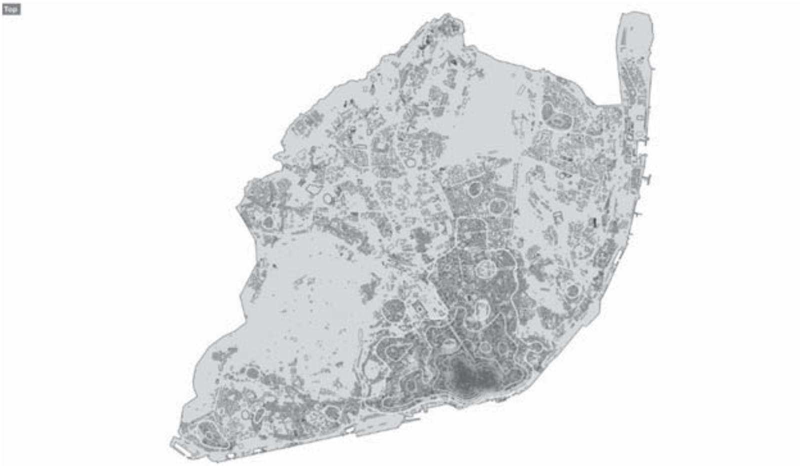


Figure 02.2

Simple KDE of building renovation in the 2010–16 period.

Although the permit database has been in use since 2003, it was not until 2009 that all the building permit types were systematically stored with correct use of the GIS IDs. Thus, to assure data consistency, only entries from 2010 to 2016 were considered. Within these bounds there are 13864 entries of which 7662 correspond to unique GIS ID entries. The large majority of duplicate GIS ID entries is a result of simultaneous processes for the same GIS ID. The reason behind this duplication is that each GIS ID is attributed to a building and all horizontal properties within it share the same code. When these entries are simultaneous it means a permit is requested for two horizontal properties in the same building. Other causes of duplicate entries in the studied timeframe are different permit applications for the same building, either in different horizontal properties or for the same property at different times. As it is not possible to reliably classify the reasons for every possible duplication, and the majority of them are simultaneous, these duplicate entries are ignored. Furthermore, only entries that have both application and permit issue date where considered, since only these entries effectively translate to building activity. For the same reason, all entries whose administrative procedure was not either "*Comunicação Prévia*" or "*Licenciamento*" were discarded.

The final set contains 4790 points for the 2010–16 period. Figure 02.2 is an example of a simple KDE that only considers Renovation events. There are a higher concentration of renovation permits in the historic centre with two distinct focus points, one over *Baixa* area and the other on *Bairro Alto*. From there spreads in all directions, but particularly so towards *Avenidas Novas* area. The higher concentration of renovation can partly be explained by the city's morphology.

Central areas have smaller plots, whereas in more recent areas the buildings are more spaced apart. The fact that only the building polygon is being considered aggravates the problem. A solution would be to attribute a weight to each point based on the building area. Yet in the database we were provided there is no information regarding the building area, or the area where renovation effectively occurred, which can be different since there is not horizontal property subdivision. These areas could be estimated for the building multiplying the area of the building polygon by the number of floors, but his can produce gross overestimations, particularly in buildings where the first floor is larger than the remaining ones.

Another problem with using building areas to determine the intensity of renovation is that renovation includes a wider range of levels of intervention than building construction. This, compounded with the fact that there is no horizontal property subdivision on the database, can lead to a different type of overestimations.

A Dual KDE sidesteps some of the previous referred issues. By dividing the KDE of renovation by the KDE of all existing buildings we are no longer determining the density in an abstract space. Instead, we are comparing the renovation permits with the existing 55385 buildings. A higher value means that a higher proportion of buildings in a given area have been renovated, consequently it is a relative measure of intensity.

In Figure 02.3, the results of both GIS and Parametric Dual KDE approaches are shown. The areas of large intensity have clearly shifted. *Bairro Alto* is no longer the location of higher intensity, instead this has shifted to the axis *Baixa-Chiado*. Also, there is a new high intensity area (above 60%) along *Avenida da Liberdade*. In fact, there is now a clear axis running along these two high intensity areas towards the river. Also, other high intensity areas appear in neighbourhoods, such as *Parque das Nações*, which previously were below 10%.

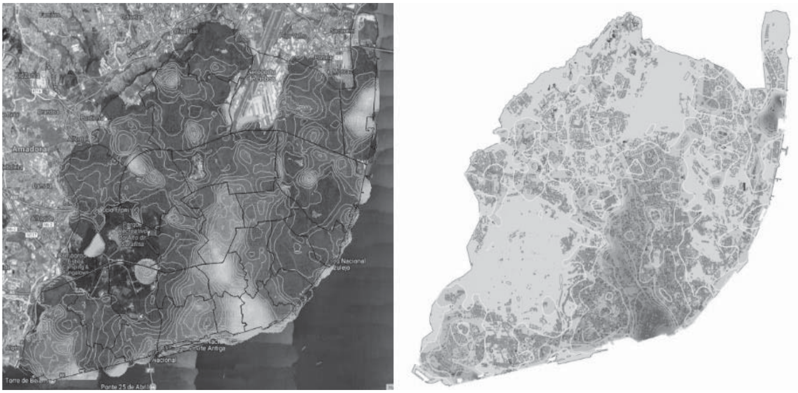


Figure 02.3

Dual KDE of building renovation in the 2010-16 period. Left: GIS; Right: Parametric modelling.

Yet, a consequence of using a relative measure is that renovation occurrences in very low-density areas, as for instance the Monsanto park, can produce strong spikes. To address this issue, we filter the low 7‰ of the city density KDE before dividing it by the Renovation KDE (Figure 02.4). Another approach suggested on the literature[11, 17] is using an Adaptive KDE, where the window width varies from one point to another. There are several ways to achieve this: one is by calculating an initial estimate and then using it as pattern for window width; another is to guarantee that each window includes at least a pre-set number of occurrences. The effect of this varying window width is that in low-density areas the kernels are flatter but wider. In future research we will seek to implement this method.

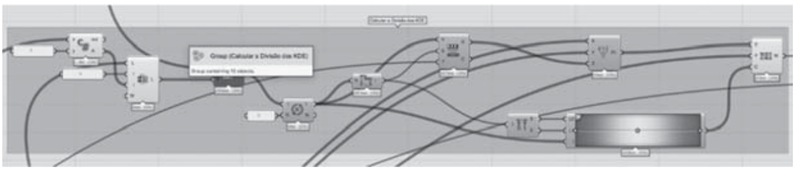


Figure 02.4

Dual KDE of building renovation in the 2010–16 period. Left: GIS; Right: Parametric modelling.

Discussion

This paper presents a method of cross-referencing city hall's alphanumerical and spatial databases, which are frequently kept apart, and producing a measure of intensity of renovation that can be visualized on a map. We propose two approaches: a GIS and a visual-programming implementation. Furthermore, the same methodology can be applied to different types of information, such as the distribution of specific types of services, offices, or shops.

The Dual KDE strikes a balance between analytic and synthetic representations, without the loss of the underlying spatial information. Furthermore, this method is capable of continuous estimations of the underlying density of a given phenomenon based on finite random samples. Additionally, the described method doesn't require deep knowledge of statistics to be used. There are sound mathematical methods in the literature to support the choice of kernel and the window width as these depend on the sample that is being analysed.[11] Yet, it is also possible to arrive at an acceptable window width by simple experimentation and visual feedback. If the purpose is gathering intuition about urban trends absolute precision is not paramount, and for a designer this is a more natural way. Furthermore, a parametric modelling environment allows for almost real-time experimentation of settings.

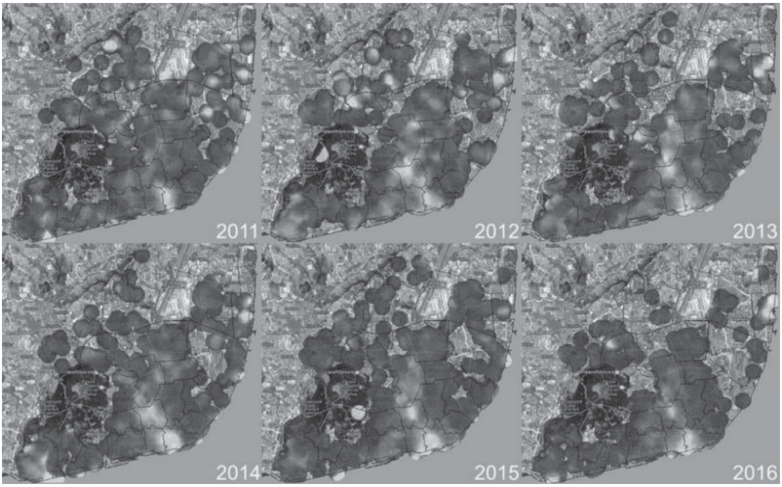


Figure 02.5

Annual Dual KDE of building renovation from 2011-16 (GIS images).

Cities are in continuous transformation, speculating on alternatives to determine if there are areas of the city where building renovation is more intense can enrich the patterns of social and urban analysis concerning planning tools and urban projects, providing a useful tool for all the stakeholders in city. The findings derived from this study would be helpful in supporting public policy-making and urban planning at the city hall level. The availability of datasets and the use of existing tools also provides the opportunity for private investors, architects, or real-estate agents of replicating these analyses in decision support.

Nonetheless, there are several limitations to this method related with the fact that distances are being measured on a two-dimensional space. Even though a relatively small window was used it is inevitable that some overflow will occur when there are neighbouring low and high-density areas. Also, this method is not appropriate for block level definition. Important avenues may have back streets, sometimes less than 100m away, which have much less intensity of renovation. Since we are using the centroids of building polygons the issue can be aggravated. An alternative would be to use points on the building border. That of course requires a sound method of determining in every instance to which street a building belongs to. In future research we aim to investigate a method of using the addresses registered on the city hall database to retrieve these points. Another way of dealing with this problem is to think of the city as a network of streets, which is, as some researchers have suggested,[18] a more accurate way of modelling the city. There is already some research on using KDE in primal networks to determine centrality.[19, 20]

To improve the accuracy of the results indirect methods of collecting more points could be used to obtain locations of renovation works that do not require building permits, such as the location of scaffolding permits. In any case, the use of cartographic databases with a greater number of points does not seem to be strictly necessary, since the calculation of KDE for annual licensing totals with only 500 or 600 points continues to provide good intensity indicators (Figure 02.5).

Acknowledgements

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References

1. INE, Estatísticas da Construção e Habitação 2015, Lisboa, 2016.
2. Lynch, K (1960) *The image of the city*.
3. Alexander, C (1965) 'A city is not a tree'. *City* 122, pp.58-62. doi:10.1017/CBO9781107415324.004.
4. Gehl, J (2011) *Life between buildings*: *using public space.* Island Press.
5. Salingaros, N A (1998) 'Theory of the urban web'. *Urban Design*, 3, pp.53-71. doi:10.1080/13574809808724416.
6. Batty, M, Marshall, S (2012) 'The origins of complexity theory in cities and planning'. In *Complex. Theor. Cities have come age*. Springer, pp.21-45.
7. Batty, M, Longley, P A (1994) *Fractal cities*: *a geometry of form and function*. Academic Press.
8. Brandão, F, Correia, R, Paio, A (2017) 'Rhythms of renewal of the city'. In *Blucher Des. Proc.*, Editora Blucher, Concepcion, pp.492-498. doi:10.5151/sigradi2017-077.
9. Rosenblat, M (1956) 'Remarks on some nonparametric estimates of a density function'. *Ann. Math. Stat.* doi:10/dgfnx5.
10. Parzen, E (1962) 'On estimation of a probability density function and mode. Ann'. *Math. Stat.,* 33, pp.1065-1076. doi:10.1214/aoms/1177704472.
11. Silverman, B W (1986) *Density estimation for statistics and data analysis*. Chapman & Hall, CRC, London, http://www.jstor.org/stable/10.2307/2347507?origin=crossref.
12. Oviasu, O I (2014) 'Using a dual kernel density estimate as a preliminary evaluation of the spatial distribution of diagnosed chronic kidney disease (CKD)'. In *Edo State, Nigeria.* GeoJournal, 80, pp.711-720. doi:10.1007/s10708-014-9590-6.
13. King, T L, Thornton, R J, Bentley, A M, Kavanagh (2015) 'The use of kernel density estimation to examine associations between neighbourhood destination intensity and walking and physical activity', *PLOS ONE*, 10, e0137402–e0137402. doi:10.1371/journal.pone.0137402.
14. Liu, K, Wang, J, Tang, P (2015) 'Sprawling urban form and expanding living space: a study on the relationship of residential space development and urban built-up area expansion in Nanjing, China'. *J. Asian Archit. Build. Eng.*, 14, pp.387-394. doi:10.3130/jaabe.14.387.
15. Thurstain-Goodwin, M, Unwin, D (2000) 'Defining and delineating

the central areas of towns for statistical monitoring using continuous surface representations'. *Trans. GIS.*, 4, pp.305-317. DOI:10.1111/1467-9671.00058.

16. Okabe, A, Okunuki, K, Shiode, S (2006) 'SANET: a toolbox for spatial analysis on a network'. *Geogr. Anal.*, 38, pp.57-66. doi:10.1111/j.0016-7363.2005.00674.x.
17. Levine, N (2010) 'Kernel density interpolation'. In *CrimeStat IV*, Ned Levine & Associates, Houston, TX, USA 2010. https://www.nij.gov/topics/technology/maps/documents/crimestat-files/CrimeStat%20IV%20Chapter%2010.pdf (accessed February 6, 2018).
18. Miller, H J (1994) 'Market area delineation within networks using geographic information systems'. In *Geogr. Syst.*, 2nd ed., pp.157-173.
19. Porta, S, Latora, S, Wang, V, Rueda, F, Strano, S, Scellano, E, Cardillo, S, Belli, A, Càrdenas, E, Cormenzana, F, Latora, B (2012) 'Street centrality and the location of economic activities in Barcelona'. *Urban Stud.*, 49, pp.1471-1488. doi:10.1177/0042098011422570.
20. Yu, W, Ai, T, Shao, S. (2015) 'The analysis and delimitation of Central Business District using network kernel density estimation'. *J. Transp. Geogr.*, 45, pp.32-47. doi:10.1016/j.jtrangeo.2015.04.008.

CHAPTER THREE

SPATIAL ANALYSIS IN GIS ENVIRONMENT: LOCATIONAL ATTRACTIVENESS ASSESSMENT OF THE RETAIL TRADE[(1)]

ELIZIÉLE PAROLI, CLARICE MARASCHIN

Introduction

Trading is one of the most primitive and fundamental social relations in human society. In contemporary cities, retail is a fundamental activity, from an economic, social, or spatial point of view. The spatial structure of cities is closely linked to the location and spatial pattern of retail establishments. The importance of this activity is highlighted in the literature as attracting movement, creating centralities, and adding revitalization in cities.

Retail location is a central topic in market geography. Once a distributor has decided where to put a store, and how big to build it, he has well set at least the range of its future profits.[1] According to Clarke, the location decision is the most important one, because the retailer must live with it and handle it continually to ensure profitability.[2] Many studies seek to identify the logic of the spatial location and distribution of trade in cities. These approaches include the gravitation models pioneered by William J. Reilly, whose work was published in 1931. This author associated Newton's universal law of gravitation to what he called attraction force between two retail centres and their potential clients. Later, David Huff improved this idea by including the attractive potential of several establishments competing by customer preference in his equations. Over time, studies have been seeking to explore the importance of several attributes that hold influence over the consumer's choice.[3] Recently, classic models like Huff's have been integrated to the

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computational environment through Geographic Information Systems (GIS), which are associated with a greater availability of georeferenced urban data.

This paper explores a methodology for spatial analysis of retail using GIS, and its objectives are: a) discussing the influence of different attributes in the consumer choice among a group of retail offers and b) developing an empirical application for the clothing retail business sector in the central area of Santa Maria, RS, Brazil. We will emphasize urban attributes rather than store attributes, focusing on three aspects of urban form: store clustering, accessibility, and topographic slope. The software ArcGIS® was used as the integrating environment for different analysis tools.

Retail Location

Factors of Retail Localisation

Numerous factors affect the performance of a retail business, which can be classified in spatial and non-spatial factors.[4] The focus of the present study lies under the spatial factors, studied by Christaller[5] and Berry[6] who analysed the trend of retail activities and services to cluster in the same area, leading to different hierarchized centres. Central place theory calls attention to an important parameter of retail location: accessibility to the consumers. In general terms, accessibility may be taken as an indicator of local development, associated to the land value, the occupation, the competition, the specialization, and the concentration[7]. The importance of accessibility in retail location is highlighted by Ikuno, that values this attribute by its convenience[8], and by Dawson[9], who moreover, classifies it as being probably the more important attribute in the consumer choice, when associated with the quality of service and competition.

One aspect related to location is store spatial agglomeration. Several studies point out the importance of retail concentration as a factor of attraction for consumers and a strategy to minimize the negative effects of the competition. Konishi attributes the success of concentrated retail centres to: a) uncertainty of the client preference, where store clustering outweighs the uncertainty associated with consumer search, and b) the expectation of low prices, where a high concentration of stores would suggest lower prices.[10] The agglomeration of different types and sizes of stores seems to influence positively the consumers choice.[11] Urban configurational studies[12, 13 14] have sought to analyse the spatial differentiation present in the street networks, identifying the relationship between the location of retail activities and some features of the urban street grid (connectivity, accessibility, centrality). Such studies have allowed a more detailed analysis of the urban space, overcoming aggregated locational analysis, based on zones and distances. Hillier considers that living centralities always have distinctive spatial components, both on the global scale (high accessibility) and local scale (high connectivity to the neighbours).[15] Van Nes suggests that a high connectivity and density of the streets are important conditions to the vitality of retail centres.[16] Porta *et al*. find positive correlation between the distribution of retail activities and some measures of centrality.[13] Some other features of urban form are more related to retail micro-localization, as the existence of land with suitable dimensions, good visibility, and flatter topography.

Analysing Retail Location Through Models

As we already mentioned, one of the pioneers in applying gravitational approaches to retail studies was Willian Reilly. For the author, given two cities that have a trade relationship with an intermediate city, the strength of this relationship will be proportional to the population of these two cities, and inversely proportional to the square of their distance to the intermediate city.[17] Despite its simplistic nature, Reilly's theory became the basis for important studies of shopping centres, sales forecasting, market area estimation, and so on[3]. In addition, a family of models derived from Reilly's approach, associated to the areas of psychology, sociology, and human behaviour, were developed, all in search of the understanding of the preference of the consumer for a certain commercial centre.[18]

Huff departs from Reilly's work proposing an alternative model, where the focus is the consumer rather than the firm[19]. He develops a probabilistic model of retail, considering the choices between alternative centres by consumer sets and determining probability surfaces associated with each centre. For the author, consumers choose between competing centres based on their "utility", which in the model is defined as a relationship between attraction factors (size of centre, e.g.) and constraint factors (travel time). In other words, each centre has a probability of being chosen, which is directly proportional to the size of the centre, inversely proportional to the distance that separates the consumer from the centre, this equation being inversely related to the relative utilities of all other competing centres. In this sense, market areas could not be conceived of as dividing into specific points (breaking points), but as overlapping and merging areas in a more realistic way. According to the model, the probability (P_{ij}) of a consumer located in the zone of origin i buy in centre j is calculated according to the formula:

$$P_{ij} = \frac{\frac{A_j^{\alpha}}{D_{ij}^{\beta}}}{\sum_{j=1}^{n} \frac{A_j^{\alpha}}{D_{ij}^{\beta}}}$$

Where:

A_j is a measure of the attractiveness of the center j, e.g. constructed area.

D_{ij} is a distance or time to travel between i and j.

α is a parameter of attractiveness.

β is a distance constraint parameter.

n is the total number of centers, including center i.

One of the main advantages of gravitational approaches is its empirical character. Huff states that few analysts, except for "gravitationalists", were able to formulate their ideas in a way conducive to empirical verification. In the next item, the methodology for the empirical application of this work is presented.

Methods

Geographic Information Systems (GIS) are on the rise for its ability to cross data from different sources and reveal underlying spatial patterns. Fast and low-cost computers associated with the growing availability of urban data and information allow the application of more detailed gravitational models, exploring the GIS functionalities to operate with data in different geographic scales[20]. Indeed, the advances in technology lead to an increase of functionalities that GIS can now perform, which allow new approaches in urban studies.[21] This paper proposes an application of the Huff model included in the ArcGIS® 10.3.1 package (ArcGIS Market Analysis Tools) aiming to discuss the influence of different attributes in the consumer choice among a collection of retail offers. As previously stated, we will focus on urban attributes rather than store attributes. We do not intend to minimize the great relevance of store attributes (store size, parking spaces, variety of goods, etc.) in consumer choice but to emphasize the urban form attributes of the location. To do this, we will take the hypothesis that all stores have a uniform retail profile.

To run the empirical application, we selected three main features of urban form related to retail location and defined their respective attributes. The selected features are agglomeration pattern of the stores (level of spatial concentration), accessibility (topological accessibility) and, as an environmental feature, the slope of the terrain. We take these parameters as measures of attractiveness in Huff model to estimate the patronage probabilities of each store (location) and then summarize how total population would be shared between stores. The Huff model calculates this market share by applying probabilities to the population data for all origins.

The study area is downtown Santa Maria, Brazil (Figure 03.1). The region concentrates the most important commercial streets since 1885, which was when a railway was built in its vicinity, giving it the title of "railway city", as well as strengthening retail and local services. Thus, from its point of origin, an area of influence of 650m radius was established for analysis, according to Figure 03.1.

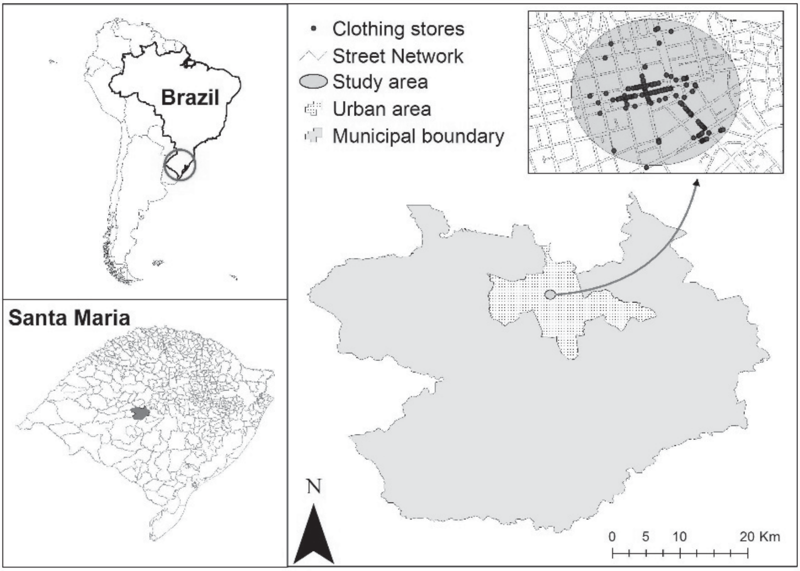

Figure 03.1

Location map of the study area.

We selected the clothing retail business sector because it represents a large amount of retail stores in downtown area and the stores are quite similar in this region (size about 100–200m^2, single owner, few retail chains, and most of them without parking spaces). A total of 143 stores were identified through a field survey during the month of May 2016 and data were checked with Google Earth Pro® images.

The level of spatial concentration of stores was estimated through the Kernel density: a method that creates a continuous field through discrete objects to analyse data concentration.[22] We organize the output in 5 classes.

The terrain slope in degrees was processed in a Digital Elevation Model (SRTM) made available by NASA with a spatial resolution of 30m.

To measure street accessibility, the first step was to create a spatial representation of downtown Santa Maria street grid. The study area was vectorized with the help of ArcGIS® Open Street Maps to generate the network. We use "street segments"—the geographic space located between two corners due to its high level of detail considering the unequal distribution of retail shops along the streets. This spatial basis contains 245 street segments and is entered as input to calculate topological accessibility in the software UrbanMetrics®.

Accessibility is a measure of relative distance (topological) from each space to all others in the same spatial system.[23, 24] Table 03.1 summarizes the study methodology.

Urban form aspects	Attribute	Input	Output	Data intervals	Classes
Store clustering	Level of spatial clustering of stores	Location of the stores - point file	Kernel density (%)	0 - 5.4901	1
				5.4901 - 18.0391	2
				18.0391 - 37.2548	3
				37.2548- 65.0979	4
				65.0979 - 99.9998	5
Accessibility	Topological accessibility	Street network - polyline file	Configurational model of accessibility	36.3214 - 43.0222	1
				43.0222 - 47.4109	2
				47.4109 - 50.4294	3
				50.4294 - 53.1654	4
				53.1654 - 57.4317	5
Environmental aspect	Terrain slope	Digital Elevation Model - SRTM	Slope (degree) of the study area	0 – 2.5751	5
				2.5751 – 4.3104	4
				4.3104 – 6.045	3
				6.0458 – 8.2851	2
				8.2851 – 14.275	1

Table 03.1

Input variables and methodology.

The ArcGIS software was the integrating environment for the different tools and data, and for the application of the Huff model. To run the Huff model, we take data on the total population by census tracts (centroids) as origins and all the 143 stores as destinations. The urban area of the municipality was included in the study. The distances are Euclidean, and the exponent used was 2. We performed four separated runs of the model; each run was loaded with one of the three attractive factors and, in the last run, all parameters were considered together. The model was able to estimate the population share for each store (location) by considering each selected attractiveness factor.

Results

Pattern of Stores Clustering

The map shown in Figure 03.2 reveals the strong concentration of clothing stores in perpendicular streets to Rio Branco Avenue, the great commercial centre of Santa Maria's "Railway City Era". In addition, there is a tendency for these stores to settle along the continuation of Rio Branco Avenue. The strong presence of empty areas also helps to demarcate the centre of the city as the heart of this activity.

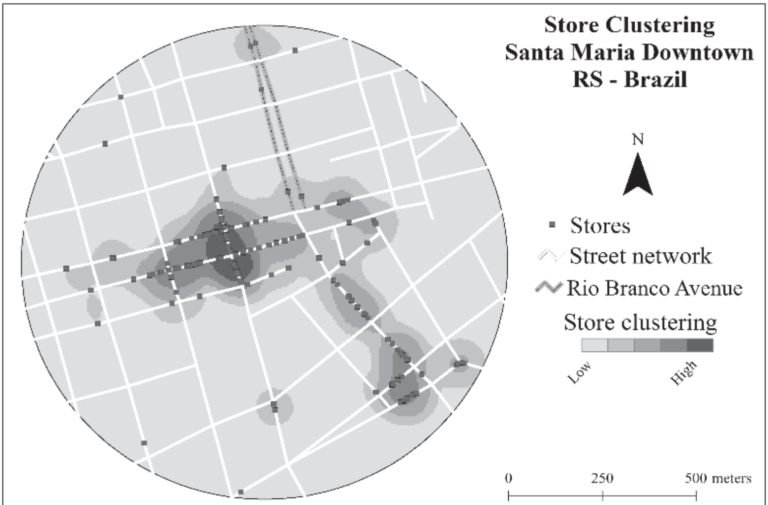

Figure 03.2

Kernel density map of clothing stores in the study area.

Accessibility

The calculated accessibility (Figure 03.3) indicates a strong correlation between the most accessible paths of the area of study and the retail locations. Out of all the stores, 40% are located on the most accessible routes in the system and, if we consider the two more accessible classes (red and orange colours in the map), this number rises to 72.73%.

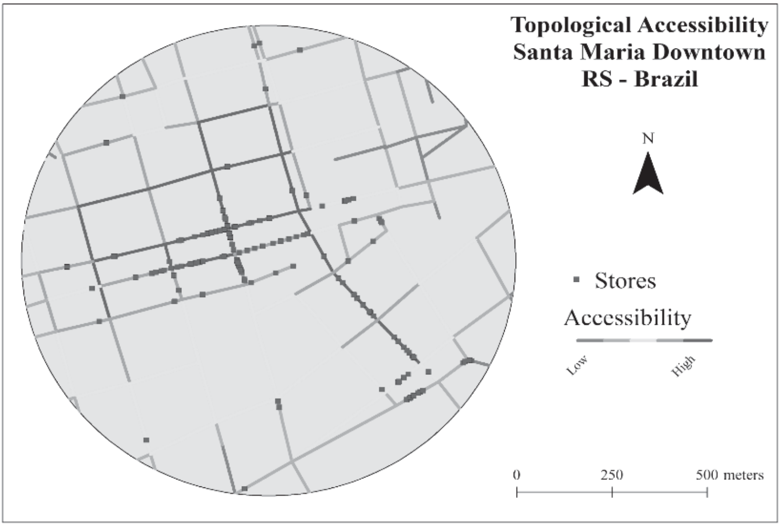

Figure 03.3

Topological accessibility.

Terrain Slope

Finally, the terrain slope analysis (Figure 03.4) demonstrates the preference of stores to allocate streets with a lower degree of slope. This is possibly to facilitate pedestrian access since this flow is intense in the region and is facilitated by the presence of two of the largest bus stops in town. With these results in hand, we set out to apply the Huff model.

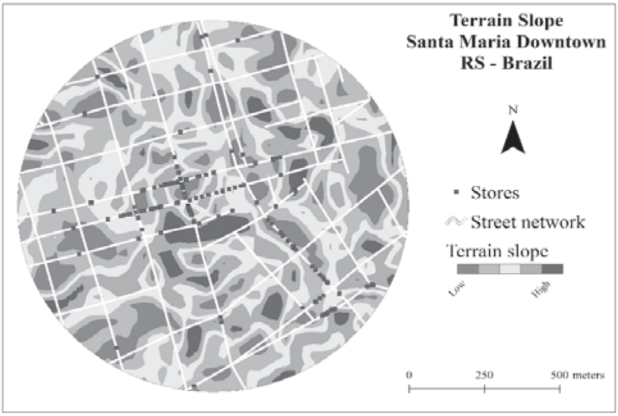

Figure 03.4

Terrain slope (source: authors based in STRM image).

The Huff Model

We used the centroid of the census tracks as origins for the Huff model, with total population data. Figure 03.5 is a map of population by census track for elucidation reasons.

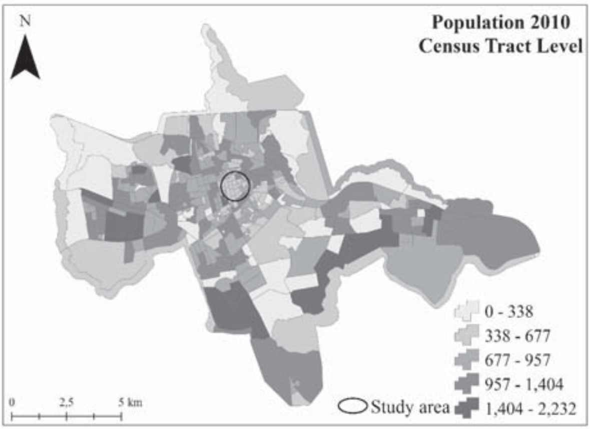

Figure 03.5

Population 2010, census tract level (source: authors based in IBGE data).

The figure shows a high concentration of people in the southern and eastern regions of the city. Also, a tendency to concentrate around the central area of the city is noted.

A visualization of the Huff model is shown in Figure 03.6. The images show the patronage probability surface (a grid) that was created for a selected store. In order to simplify the visualization, we show this probability surface for store 24 when competing with two other establishments: first by considering each attracting variable at the time, and then simultaneously.

Figure 03.6

Map of customer patronage probabilities for store 24 (source: authors based on the Huff model; ArcGIS® Market Analysis Tools).

Although at the first glance the images look quite similar, we can begin to observe some peculiarities; for example, in this case, Store 24 seems to have more probability of choice when it only considered the variable terrain slope, and less when only considering topological accessibility. This example illustrates how the analysis can be different when looking at various parameters. Now, imagine how it different the images would look like with all the 143 stores compared collectively. This is the reason why we decided to illustrate the methodology with just a few stores competing with each other. Table 03.2 summarizes the probable population share to each store as estimated by Huff model an based on the sum of probabilities for all origins. For simplification purposes, we are only illustrating the ten best ranked stores.

Store clustering		Topological accessibility		Terrain slope		Variables in conjunction	
Stores	**Attracted population**	**Stores**	**Attracted population**	**Stores**	**Attracted population**	**Stores**	**Attracted population**
Store (19)	2,555	Store (115)	2,442	Store (82)	2,996	Store (79)	2,381
Store (21)	2,547	Store (60)	2,438	Store (41)	2,674	Store (52)	2,381
Store (76)	2,543	Store (78)	2,359	Store (16)	2,597	Store (123)	2,378
Store (79)	2,539	Store (133)	2,342	Store (0)	2,512	Store (91)	2,368
Store (52)	2,538	Store (127)	2,313	Store (51)	2,505	Store (97)	2,367
Store (53)	2,536	Store (80)	2,288	Store (80)	2,488	Store (80)	2,317
Store (123)	2,535	Store (6)	2,277	Store (96)	2,488	Store (6)	2,305
Store (3)	2,534	Store (59)	2,274	Store (32)	2,488	Store (61)	2,299
Store (33)	2,527	Store (28)	2,272	Store (6)	2,475	Store (76)	2,226
Store (91)	2,525	Store (61)	2,271	Store (59)	2,475	Store (53)	2,220
Sum	25,379		23,276		25,698		21,022

Table 03.2

Estimated population share for top 10 stores, according to selected attraction parameters (first line) (source: authors based in Huff model; ArcGIS® Market Analysis Tools).

Here, we observe that the terrain slope variable, when considered alone, has a greater population share than the other variables, even when we consider all the variables together. In other words, it suggests that, in this particular case, stores located in flatter areas have a better performance in population attraction. The difference of the population shares of the most auspicious store when only considering the terrain slope and topological accessibility comes to 22.69%; when compared to store clustering comes to 17.26%; and to all the variables in conjunction, it comes to 25.81%, thereby reinforcing the preference for plain localities.

As expected, the analysis of the top 10 stores when we consider all the variables together shows only stores that computed a maximum value for each variable separately. This rank shows that 10 stores appear repeatedly in different columns, wherein stores 6 and 8 are the most remarkable of the set. This frame can help us to identify which factors are the most important for a consumer when choosing between establishments.

Probable attracted population considering	Measures of Central Tendency			Measures of Dispersion		
	Mean	Mode	Median	Standard deviation	Coefficient of variation	Range
Store clustering	1,762.287	#N/D	1,998.479	568.974	0.323	2,034.776
Topological accessibility	1,762.287	#N/D	1,812.856	498.359	0.283	1,982.356
Terrain slope	1,762.287	#N/D	1,862.684	537.752	0.305	2,526.099
Variables in conjunction	1,762.287	#N/D	1,825.091	354.165	0.201	1,599.370

Table 03.3

Values of central tendency and dispersion measures.

Lastly, we describe the statistics analysis for the dataset of all the 143 stores (Table 03.3). Since this table was generated for each origin point (census tract centroid; total population data), it makes sense that the mean of each dataset is the same, since it is the mean of the total population. A few remarks: no dataset had repeated values (mode), which underlies the heterogeneity of the attracted population by each variable analysed. Also, on average, store clustering alone is responsible for attracting the most people, and topological accessibility the least. However, the measures of dispersion reveal that store clustering is the variable for the greatest dispersion from the mean-standard deviation and the coefficient of variation, which suggests a higher degree of variability among the data. As expected, when analysing all three variables together, the data variability tends to decrease.

Discussion and Conclusions

In this paper, we explored the Huff model to discuss the urban form attributes of store locations. Through the literature review, we selected three attributes of the retail location by trying to identify differences in their consumer attraction potential. The separate runs of the Huff model allowed us to notice the relative uniform performance of all three attributes. However, in this specific case, the terrain slope was revealed to be a stronger attractor than the other ones. These results are supported by studies showing that streets with a high slope tend to discourage pedestrians,[25, 26] and, in general, they are not favourable for retail location. The attribute of topological accessibility proved to be relevant, and it can be considered as a complement of the traditional measure of distance in Huff's model. This reinforces the role of distance in store choice.

The results also show that there are some stores whose locations perform better than others, such as stores 80, 59, and 6, which are present in two of our three rankings. But no store achieved top 10 in all three attributes, which points to the complexity of urban form and the difficulty for retailers to find a location that meets all the recommended urban attributes.

One of the most interesting facts about the GIS application of the Huff model is its ability to easily generate different scenarios to test and discuss selected parameters of consumer attraction. This application differs from the traditional use of the model, in which the attractiveness variable generally refers to the store itself and the urban attributes appear as distance. We opted for this approach in order to study the influence of urban criteria in consumer choice. Further studies could consider both approaches in order to maximize the truthfulness of the model. The application allowed us to build different scenarios of consumer patronage and discuss the performance of the selected urban form parameters. We could also analyse these parameters individually and collectively to give the model more realism.

In order to perform the application, some simplifications were adopted. We did not explore the calibration of the variables and the adjustment of the model since no empirical research on consumer patronage was available. We must say that the variables used in this work were adequate, but they do not come close to describing the complexity of the problem. Future studies can enrich the methodology with the addition of other variables described in the literature as "influencers of areas of attraction", with a focus on the store rather than on the urban attributes, such as the buildings and the number of employees.

The urban planner's task when managing the relationship between retail and urban spaces is quite complex. Studies of the kind presented here can contribute to a better understanding of that relationship, as well as exhibit the advantages of using GIS.

References

1. McKinsey, Company & Corporation, G F (1963) *McKinsey-General Foods Study: The Economics of Food Distributors*. General Foods Corporation. Retrieved from https://books.google.com.br/books?id=6ZREAAAAIAAJ.
2. Clarke, I (1995) 'Deconstructing retail location decisions'. In *2nd Recent Advances in Retailing and Services Science Conference*. Broadbeach, Australia, pp.11–14.
3. Brown, S (1992) 'The wheel of retail gravitation?'. *Environment and Planning A*, 24(10), pp.1409–1429.

4. Mejia, L, Benjamin, J (2002) 'What do we know about the determinants of shopping centre sales? Spatial *vs*. non-spatial factors'. *Journal of Real Estate Literature*, 10(1), pp.1–26.
5. Christaller, W (1966) *Central places in southern Germany*. Prentice-Hall.
6. Berry, B J L (1967) *Geography of market centres and retail distribution*. Prentice Hall.
7. Hansen, W G. (1959) 'How accessibility shapes land use'. *Journal of the American Institute of Planners*, 25(2), pp.73–76.
8. Ikuno, S H (1987) *Análise de localização varejista: uma base urbana*, PhD Thesis.
9. Dawson, J (ed) (2012) 'Retail geography'. *RLE Retailing and Distribution*, 7. Routledge.
10. Konishi, H (2005) 'Concentration of competing retail stores'. *Journal of Urban Economics*, 58(3), pp.488–512.
11. Arentze, T A, Oppewal, H, Timmermans, H J P (2005) 'A multipurpose shopping trip model to assess retail agglomeration effects'. *Journal of Marketing Research*, 42(1), pp.109–115.
12. Hillier, B (1996) *Space is the machine*: *a configurational theory of architecture*.
13. Porta, S, Strano, E, Iacoviello, V, Messora, R, Latora, V, Cardillo, A, Wang, F, Scellato, S (2009) 'Street centrality and densities of retail and services in Bologna, Italy'. *Environment and Planning B*: *Planning and Design*, 36(3), pp.450–465.
14. Scoppa, M D., Peponis, J (2015) 'Distributed attraction: the effects of street network connectivity upon the distribution of retail frontage in the City of Buenos Aires'. *Environment and Planning B*: *Planning and Design*, 42(2), pp.354–378.
15. Hillier, B (1999) 'Centrality as a process: accounting for attraction inequalities in deformed grids'. *Urban Design International*, 4(3-4), pp.107–127.
16. Van Nes, A (2005) 'Typology of shopping areas in Amsterdam'. In *Proceedings Space Syntax*: *5th International Symposium*.
17. Reilly, W J (1931) *The law of retail gravitation*. WJ Reilly.
18. Baker, R (2006)'An introduction to retail and consumer modelling'. *Dynamic trip modelling*: *from shopping centres to the internet*, pp.21-76.
19. Huff, D L (1964) 'Defining and estimating a trading area'. *The Journal of Marketing*, pp.34–38.
20. Dramowicz, E (2005) 'Retail trade area analysis using the Huff model'. *Directions Magazine*, 2.

21. Vitalli, K, Lena, H (2016) 'The value of location: spatial analysis of urban morphology for retail development'. In *Proceedings of the IRES International Conference*.
22. Longley, P A, Goodchild, M F, Maguire, D J, Rhind, D W (2009) *Sistemas e ciência da informação geográfica*. Bookman Editora.
23. Hillier, B, Hanson, J (1984) *The social logic of space*. Cambridge: Press Syndicate of the University of Cambridge.
24. Krafta, R (1994) 'Modelling intraurban configurational development'. *Environment and Planning B*: *Planning and Design*, 21(1), pp.67–82.
25. Cervero, R, Duncan, M (2003) 'Walking, bicycling, and urban landscapes: evidence from the San Francisco Bay Area'. *American Journal of Public Health* 93(9), pp.1478–1483.
26. Larrañaga, A M, Rizzi, L I, Arellana, J, Strambi, O, Cybis, H B B 'The Influence of built environment and travel attitudes on walking: a case study of Porto Alegre, Brazil'. *International Journal of Sustainable Transportation*, 10(4), pp.332–342.

CHAPTER FOUR

URBAN SEGREGATION AND SOCIO-SPATIAL INTERACTIONS: A CONFIGURATIONAL APPROACH[(1)]

ANA LUISA MAFFINI, CLARICE MARASCHIN

Introduction

Segregation is an inherent feature of cities and it has been the focus of interest in different scientific fields. It can be based on ethnic, racial, economical, religious, gender, among other reasons. Freeman[1] defines segregation as restriction of interaction involving or not the physical space. In architecture and urban planning studies, urban segregation is commonly approached as separation.[2, 3] Segregation is the separation of people, activities and functions[4] and it can hardly be approached without its spatial aspect. Villaça[5] defines urban segregation as any form of exclusion that manifests itself in a spatial manner in the city.

Historically, urban segregation studies analyse the locational patterns of housing, without taking into consideration the other patterns where it can be manifested, such as the separation of activities and functions. In more recent decades, the advance in technology allowed for new ways to study the city. The increase in computational capacities, the development in the field of Geographical Information Systems (GIS), among others, are crucial to the study of cities, which allowed for new and innovative ways to study segregation and its implications[6]. These morphological configurational approaches enable a description of segregation taking into account the relationship between people and activities in space. The shift in focus of the segregation problem, from purely residential to a broader problem, which

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encompasses the daily routines of individuals and their movement in the public spaces, is a welcome change. The way we interact with individuals from different social groups shapes our perception of the others, creating the capability for us to feel solidarity for them or not. In the words of Sibley[7] (p.116), “space is an integral part of the outsider problem. The way in which space is organised affects the perception of the ‘other’, either as a foreign and threatening, or as simply different”.

The present paper intends to analyse segregation from a shift in emphasis from traditional territorial and housing segregation to segregation as a restraint of socio-spatial interactions, thus including other facets of the phenomenon of segregation that have not yet been explored and seeking new forms of evaluating and measuring this segregation in a spatially more relevant way. The paper aim is to: a) present a methodology of analysis of segregation based on configurational models, and b) develop an empirical application in a small Brazilian city, Ibirubá. The paper opens with a review of main urban segregation studies and how they are approached and goes on to the urban spatial configurational studies. The following chapters will explain the proposed configurational methodology, its measures, the process of modelling, and initial results and discussion. The paper ends with an analysis of the potential for the methodology and its limitations.

Segregation and Urban Spatial Configuration

In Latin America the attributes that characterised segregation are mainly socioeconomic, and, despite being the largest economy in Latin America, Brazil ranks among the highest indicators of income inequality in the world.[8, 9] According to the 2010 PNUD report, Brazil is the tenth more unequal country in the world and the first in income concentration among the richest 1% of the population. These inequalities have a strong implication in the spatial configuration of cities.

The study of urban segregation has many facets, but two approaches stand out in the scientific field, the sociological and the geographical one.[10] The sociological approach considers segregation as the absence of interaction between individuals of different social groups. The geographical approach considers segregation as the unequal distribution of social groups in the urban space. These two approaches tend to be used apart from one another, and among them the geographical approach is the one that is most commonly used.

Most existing studies of urban segregation have their main focus on residential locations. The spatial aspect of urban segregation is usually assumed as the uneven locational housing patterns. There are many examples on this type of study, one of the most known is the study of the city of Chicago with its concentric rings[11]. These approaches of residential segregation are the main approach for urban segregation in the undeveloped cities of Latin America. However, the spatial patterns in these cities are different than those from North America and Europe. In Brazil, the urban segregation was first characterised by its unequal housing standards. Around 1940, with the growth of urban population and the movement of people from rural to urban areas, the city emphasised its segregation patterns, with the rich population living in the downtown area and the poor in its periphery. In more recent years the pattern changed. The spatial distance between the different groups shrunk, the rich started moving towards a more suburban area (although not the same suburb as in North America), and the new urban pattern is of "enclaves". The enclaves create a new form of segregation, where people are closer, but separated by physical barriers, and security control systems.[12, 13]

In an attempt to fight social inequality some governmental policies were implemented in the country. In the urban segregation field, the main policy is residential, to provide more dignified houses for the poorest groups. The reduction in the inequality indexes did not accompany the increase access to housing in the same speed. There are many reasons for this not to happen (which will not be addressed in this paper), but among them is the spatial issue of urban segregation.[13, 14, 15]

With the relative physical approximation between different social groups (Vaughan, 2011), segregation as purely housing locational patterns is no longer capable of explaining the hole reality of urban segregation. This context reinforces the idea of urban segregation as the absence of interactions in space, or as the exclusion to opportunities of access to activities and services in the cities.[8, 1, 16, 17] Feitosa and Lisboa[18] studied segregation as spaces of activities, analysing the indexes of evenness/ clustering and exposure/isolation.

Cities are *not only for living but also for other activities of which some make an impression in public space, such as working, travelling, walking, shopping, socialising, and recreational activities*[4] (p.2). When we comprehend that individuals move around the city, we start to analyse urban segregation by the individuals' relations and interaction with one another and with space itself.

Configurational theory[19, 20] has contributed to urban segregation studies. The spatial configurational studies of segregation do not replace the others approaches, but they arise to broaden the understanding of the segregation phenomena. These studies try to describe how the interactions between different social groups can happen in the city. Usually, this interaction is measured by the levels of co-presence in the city. When individuals of different social groups can see one another, even if they do not directly interact, they can develop empathy for each other, which is an important step in fighting social inequality.[21, 8, 22]

Among the recent research into urban segregation are the studies of co-presence based on the number of individuals from different social groups that pass by the same location. These studies consider the daily routines of individuals and try to identify the importance of the spatial configuration of cities by comparing it with some Spatial Syntax measures, such as accessibility and betweenness.[21] These properties measure the physical and spatial attributes of cities.

Netto[22] presents the study of segregation with a focus in the possibility of encounters between different individuals. He uses big data from social media to identify the movement of individuals and then, using spatial configuration, measures the possibility for these encounters.

Urban configurational models are simplified representations of reality, which implies a certain level of abstraction.[23, 24] Configurational models assume the city presents a hierarchical pattern of spatial differentiation (configuration) influencing another aspects, as pedestrian movement and land uses. Such models apply methodologies of disaggregating the city into components (basic units of space, spatial attributes) and their relationships (topological descriptions, adjacencies, centrality). Graph theory provides the analytical basis for the calculation of different measures and properties of the urban network. The models assume the shortest path hypothesis, i.e., the connections between cells of the network will always be made by the shortest paths. Thus, any city would exhibit a spatial differentiation, i.e., a hierarchy in which some cells (spaces) are distinguished by their relative position and/or the number of connections with others.[20]

Based on the pre-existing configurational studies of cities, the present paper aims to develop a methodology that evaluates urban segregation by measuring the possibilities of encounters between individuals from different social backgrounds in public spaces. This paper focuses on the daily routines from residences to retail places.

To measure the possibilities for co-presence, we identify the most likely routes individuals would take from their houses to retail places through the model of Centrality. According to Freeman[25], centrality is the property of a cell being along the path that connects two other cells, and their hierarchy is given by the total number of times this one cell appears in the paths connecting all pairs of cells of a system. Krafta[20] proposes a weighted Betweenness Centrality (Freeman-Krafta Centrality), introducing the notions of tension and distance: the tension reflects the relationship between two points expressed by the product of its contents (attributes); the distance refers to the extension of the shortest path between each pair of points, and this increases as the centrality of each cell interposed in the path decreases. The Freeman-Krafta Centrality is expressed by the equation:

$$t_{ij} = a_i . a_j \qquad t_{ij}(K) = \frac{a_i . a_j}{p} \qquad C(K) = \sum_{\substack{i.j \\ i<j}}^{n} t_{ij}(K)$$

Where t_{ij} is the tension between two units (i and j) of space, ai and aj are the amount of built form respectively in i and j, computed with their respective attributes $t_{ij}(K)$ and the piece of tension between i and j attributed to K, where K is a unity of space belonging to the shortest path between i and j, p is the number of unities of space belonging to those shortest paths. Finally, C(K) is the centrality measure of K, given after the computation of all possible pairs of the system. The model allows computing the tension generated between activities system, working as an indicator of the social flow of individuals moving through the spatial system to perform these activities.[26]

In this paper, we develop a first application focusing on the relationship between residences and retail locations. The model also allows differentiating space attributes such as the level of retail attraction (example, shopping centres can be modelled as more attractive than a grocery store). The same principle can be used to classify residences by density or income, for example.

Methodology

This paper presents a methodology of analysing segregation based on configurational models. We use a Centrality model to represent the probabilities of interaction between individuals from different socio-economic strata in the city of Ibirubá, Brazil. We build two scenarios, regarding high- and low-income resident's flows to retail shops. Comparing these two scenarios allow us to identify spaces with higher and lower potentials of interactions in the city, providing a first measure of segregation. This methodology requires the city to be represented as a network, defining the discrete units of urban space to be used, according to the study objectives. We use “street segments”, the geographic space located between two corners. The choice of this spatial unit is due to its high level of detail considering the very unequal distribution of retail shops along the streets.

A street map provided by IBGE (Brazilian Institute of Geography and Statistics) was updated using Open Street Map (ArcGIS r.10.1), to generate the network of segments. This spatial basis contains 711 street segments (Figure 04.1).

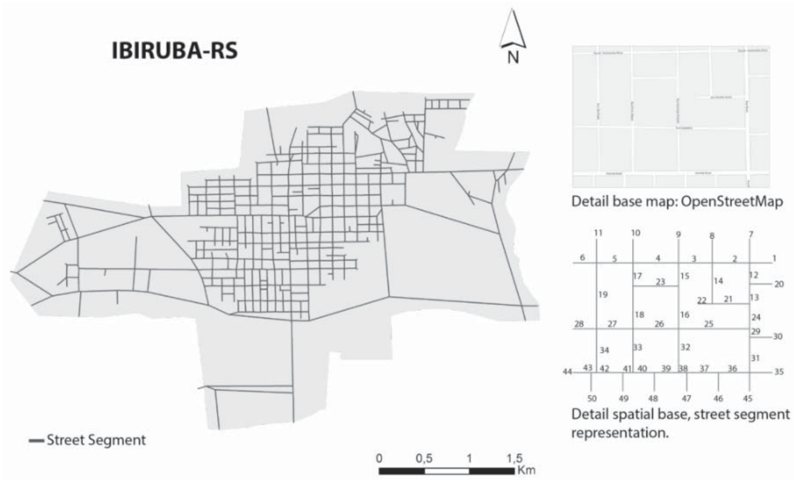

Figure 04.1

Spatial representation of the city of Ibirubá by street segments (left) and detail (right) (source: authors based in Open Street Maps).

As the spatial basis is finalised, the empirical data to compose the attributes must be collected and organised for each street segment. Data on residents correspond to the amount of population in each street segment of the city. This data was obtained through the 2010 IBGE Census referring to the number of residents per census tract. IBGE also provides the digital network of these sectors in the shapefile format, which was imported into the same GIS environment. Total population of each census tract was equally distributed between the street segments included in its area. Residents were also distinguished by income strata. We estimated an average household income for each census tract by dividing the total income by the number of dwellings in each census tract. Then we classify the results in three categories (in minimum wages): a) low (up to 3.5mw); b) medium (from 3.5 to 6.0mw) and c) high (above 6.0mw). We will compare only high- and low-income strata. Data on retail establishments were obtained through field research in June 2017. All the 352 retail shops had their address recorded and were spatially located in each street segment. After this preparation, data relating to the attributes of population and retail activities were organised into tables in the GIS environment (.xml format) and imported to the software Medidas[27] to perform the configurational analysis. This software allows linking a database to the spatial basis, enabling the insertion of loads into the spatial units to represent the spaces different attributes. Thus, the amount of retail establishments and residents in each street segment is calculated as loads.

In this paper we considered all the retail establishments with the same attractiveness (weight 1.0 in the model), regardless of their size.

The residential locations were considered by their income group (low, medium, high) and, based on their locations, received weight 1.0 in the model. For the calculation of the distances, we used the geometric distance between each pair of street segments.

The results obtained by applying centrality model were re-introduced into the GIS platform, and the relationship between the spatial system and the socioeconomic data were analysed and evaluated.

Two basic scenarios (thematic maps) were produced, which are presented in the next section.

Results

Empirical Study

The municipality of Ibirubá is located in the south of Brazil. It has three main districts and a population of approximately 20000 inhabitants. Figure 04.2 shows the location of the city.

The city's economy is based on agriculture and agribusiness. In Figure 04.3 we can see the distribution of income in the housing locations. There is a large concentration of the high-income strata in and around the downtown area and in the southeast side.

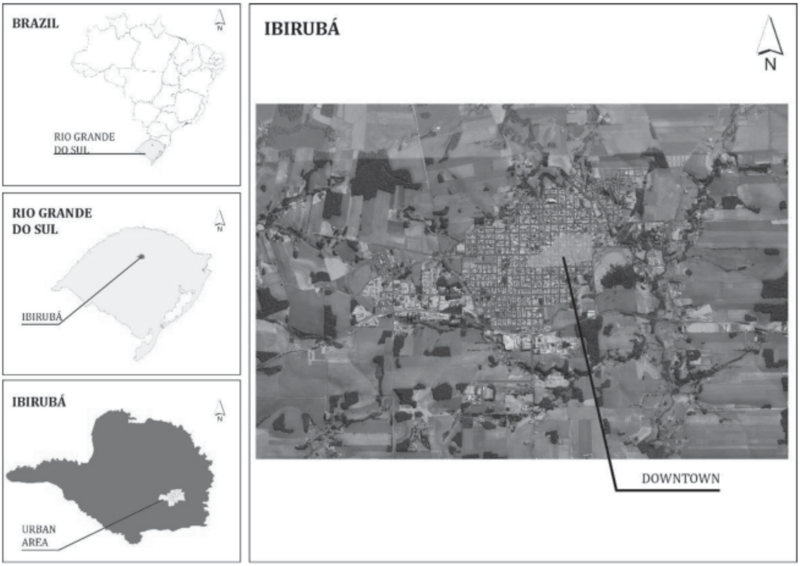

Figure 04.2
Ibirubá location.

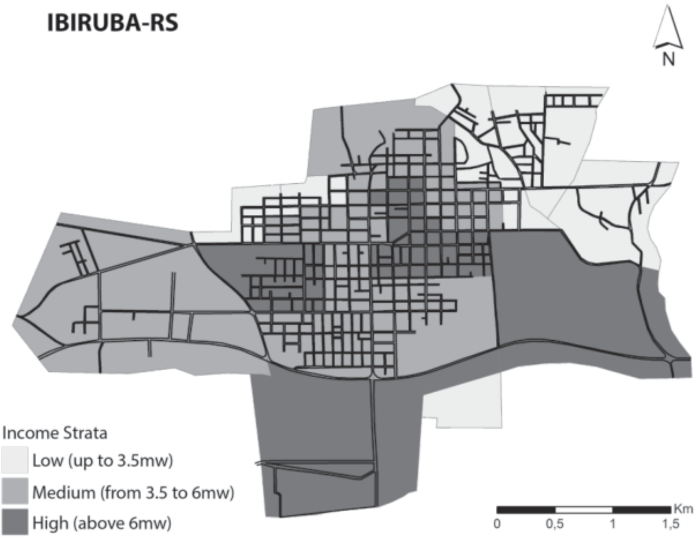

Figure 04.3
Ibirubá by its income strata (source: authors based in IBGE, 2010).

The retail sector is constituted mainly of small family-owned shops and some larger shops, such as supermarkets and furniture stores. Figure 04.4 locates the retail establishments, and we can notice a concentration in the downtown area and in two main avenues (N-S and E-W).

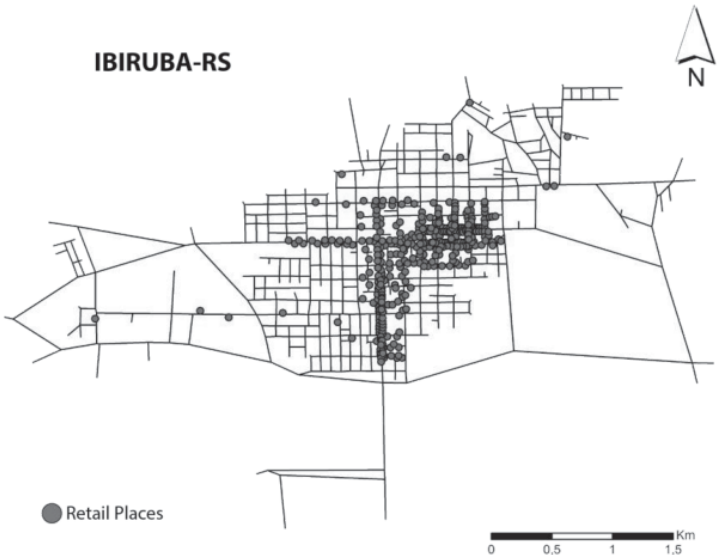

Figure 04.4

Location of the retail establishments.

The weighted centrality results for the high-income strata showed a strong concentration in the central commercial area and its adjacencies, but it also showed that this income group probably does not move in the more peripheral area of the city when going to the retail establishments. Figure 04.5 shows the map with the results, which were classified in 4 categories by natural breaks. When analysing the weighted centrality results for the low-income strata in relation to retail establishments, it was possible to see a change in the results. Figure 04.6 shows that, although the central commercial area is also important, we can see that some peripheral segments gain importance, and the segments of the neighbourhoods were the high-income group lives start losing importance in the results. The results were also classified by natural breaks in 4 categories.

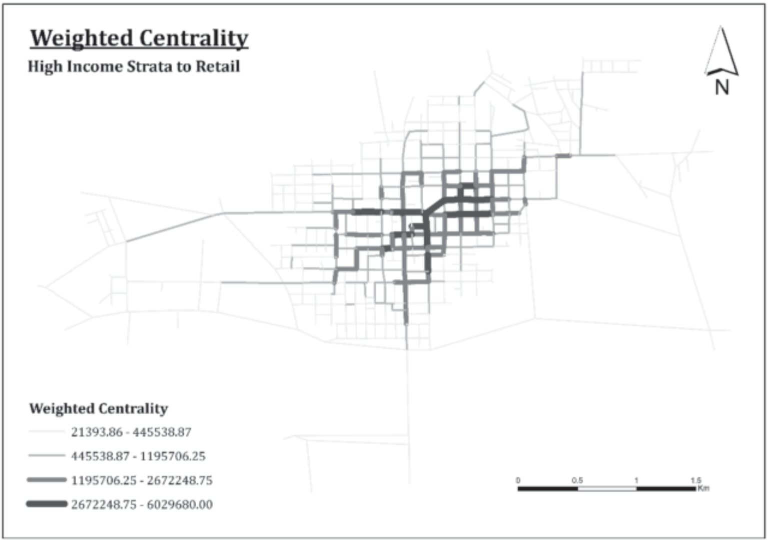

Figure 04.5
Weighted Centrality for high income strata.

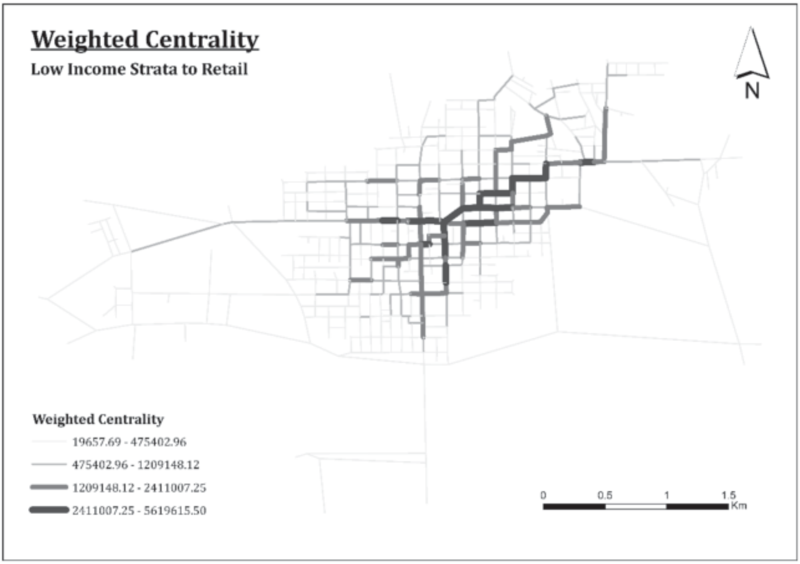

Figure 04.6
Weighted centrality for low-income strata.

Discussion

For the comparison of results, we chose a bivariate map analysis. The results of the weighted centrality for high income were transformed into three groups (1, 2, 3) and the results for the low-income group were also transformed into 3 groups (A, B, C). Figure 04.7 explains how they relate to one another. For this paper we were interest in the results in the 1A, 1C and 3A categories, for they would demonstrate the street segments where it would be most likely to happen an encounter (1A), and so, show us the least segregated area; and the street segments were encounter was least likely to happen (1C, 3A), or the most segregated areas in the city. Figure 04.8 shows the map with the comparison results.

The comparison showed that there were no segments in the 1C and 3A categories, which lead to the conclusion that the city is not segregated when analysing the probable interaction residences-retail establishments. The results also showed us that the highest centrality values for both groups (1A) occur in segments located in downtown area, which indicates that people from different income groups probably encounter one another when going to retail establishments in Ibirubá.

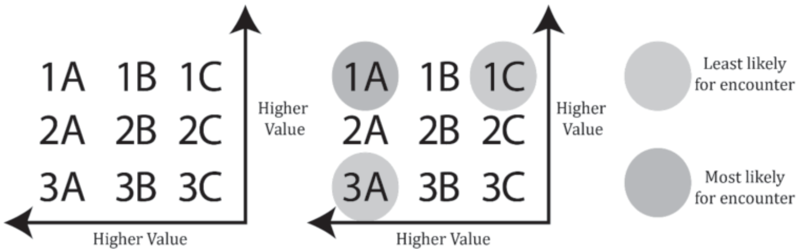

Figure 04.7

Division for analysis.

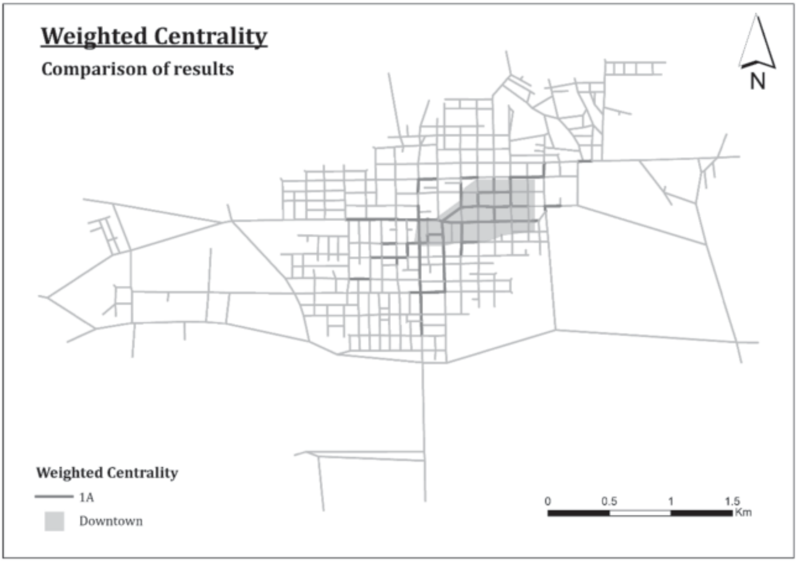

Figure 04.8

Street segments with highest centrality simultaneously for both income groups in the relationship residences-retail.

We must take into account that we are dealing with a small city, which exhibits short walkable distances. Retail establishments tend to choose their location in order to obtain maximum accessibility for the whole population, in this case, downtown area. Although Ibirubá demonstrates some preferential regions for higher income groups, the city still does not show a residential segmentation. Our results show that both income strata seem to share the same spaces when moving to shopping. According to the retail location literature, store owners are expected to locate at points of maximal accessibility to their demand; leading to spatial arrangements such as poles, corridors and specialised areas[28]. As a small city, Ibirubá retail agglomerations locate at downtown area and also along some main corridors (main avenues connecting the city to the surrounding region). In this way, general urban form of Ibirubá could be characterised as an initial stage in the urban growing process, a compact city around downtown. As the city grows, increasing distances make it viable to offer services farther from downtown. In this process, land prices and accessibility tend to influence the selection of the type of activities and users who can afford specific areas of the city. High and middle classes will make their residential location choice based on some criteria such as distance to downtown, environmental qualities, etc. Low-income families will have little choice in this scenario, living in poorly infrastructured areas. Although our paper did not identify this segregation in Ibirubá at present, we may expect it as a trend, as the income segregation on land access is a feature of Brazilian cities.

Conclusions

With this paper we aimed to demonstrate how a configurational methodology could be used for identifying and analysing urban segregation. The case of Ibirubá showed us that, in this particular small city in Brazil, there is no segregation when it comes to where people move to shop. This methodology allows the comparison of spatial factors and social attributes, and it could be used to study and compare different scenarios created by different attributes, such as shopping, working, studying, etc. However, modelling implies simplifications. In this paper we considered all retail establishments to be equal, regardless of their size; also, we accounted all the population as the origin of movement, without separating those who are leaving the house for shopping from those who are staying at home. There is also the case of how people move. Individuals from the high-income strata tend to move using their automobile vehicles, while the low-income strata tend to walk or use the public transport system. All these differences were not accounted in this paper, but the methodology allows for all these distinctions, all the researcher need is the data.

References

1. Freeman, L. Segregation in social networks. Sociological Methods & Research, v.6, n.4, 1978, pp.411-429.
2. Fainstein, S. The just city. Cornell University Press, 2010.
3. Feitosa, F. et al. Global and local spatial indices of urban segregation. International Journal of Geographical Information Science, 21:3, 2014, pp.299-323.
4. Legeby, A. Urban segregation and urban form. Doctoral dissertation, KTH. 2010.
5. Villaça, F. A segregação urbana e a justiça (ou a justiça no injusto espaço urbano). Revista Brasileira de Ciências Criminais, ano11., n.44, 2003, p.341-346.
6. Vaughan, L.; et al. Space and Exclusion. Area, v.37, n.4, 2005, pp.402-412.
7. Sibley, D. Outsiders in society and space. In: Anderson K.; Gale F.

(eds.) Inventing Places: Studies in Cultural Geography. Wiley, 1992.
8. Vaughan, L.; Arbaci, S. The challenges of understanding urban segregation. Built Environment 37(2). 2011, pp.128-138.
9. Feitosa, F. et al. Countering urban segregation in Brazilian cities. Environment and Planning B: Planning and Design, v.39, 2012, pp.1131-1150.
10. White M. The measurement of spatial segregation. American Journal of Sociology, v.88, n.4, 1983, pp.1008-1018.
11. Burgess, E. Residential segregation in American cities. The Annals of the American Academy of Political and Social Science, v.140, n.1, 1928,
12. Caldeira, T. Cidade de muros. Editora 34, 2000.
13. Sposito, M.; Góes, E. Espaços fechados e cidades. Unesp, 2013.
14. Sposati, A. Pobreza e desigualdade no século do desperdício. 32 International Conference of Social Welfare. Brasília. 2006.
15. Villaça, F. São Paulo: segregação urbana e desigualdade. Estudos Avançados 25(71), 2011.
16. Krafta, R. Spatial self-organization and the production of the city. Cybergeo: European Journal of Geography. 1999.
17. Feitosa, F.; Lisboa, F. Para além da perspectiva residencial. Revista Brasileira de Cartografia, n.68/4, 2016, pp.797-813.
18. Feitosa, F.; Lisboa, F. Para além da perspectiva residencial. Encontro Nacional da ANPUR. São Paulo, 2017.
19. Hillier, B.; Hanson, J. The social logic of space. Cambridge University Press. 1984.
20. Krafta, R. Modelling intraurban configurational development. Environment and Planning B: Planning and Design, v.21, 1994, pp.67-82.
21. Legeby, A. et al. Characterizing urban centres. 11 Space Syntax Symposium. 2017.
22. Netto, V. The social fabric of cities. Routledge, 2017.
23. Echenique, M. Modelos matemáticos de la estructura especial urbana. Ed. S.I.A.P. 1975, pp.1-13.
24. Batty, M. Cities and complexity. The MIT Press. 2005.
25. Freeman, L. A set of measures of centrality based on betweenness. Sociometry, 1977, pp.35-41.
26. Netto, V.; Krafta, R. Segregação dinâmica urbana. Revista Brasileira Estudos Urbanos e Regionais. 1999.
27. Polidori, M. et al. Medidas Urbanas. V.1.5. Software. FAUrb-UFPel. 2001.
28. Berry, B. Geografia de los Centros de Mercado y Distribución al por Menor. Ed. Vicens-Vives, Barcelona, 1967. pp.105-115.

CHAPTER FIVE

DESIGN STRATEGIES AND SEXISM IN DOMESTIC SPACES: A CRITICAL ANALYSIS OF THREE MODERNIST SOCIAL HOUSING ICONS

LARISSA GOMES, ANA LUÍSA ROLIM

Introduction

Men have always had places of authority, privacy, and leisure inside the house, while women, besides not having a space of their own, are always linked to service rooms.[1, 2] Analysing humanity, even in older societies, domestic spaces have quite often reflected the condition of subordination of women to men by reinforcing gender stereotypes and perpetuating traditional family values.

If patriarchy characterises our society and housing collectively reflects this society, what is the influence of architecture in the sexist construction of housing? To fight the notion of unpaid work at home as a key mechanism of women's oppression, new strategies for the design of domestic spaces were developed in the twentieth century. Collective spaces, such as kitchens and laundries, emerged to dissociate women from household activities. In this context, three social housing projects, which are the focus of this paper, featuring collective laundries, communal kitchens, gymnasiums, and common living spaces are noteworthy: Narkomfin, in Russia, the Mendes de Moraes complex, known as Pedregulho, and the *Unité d'Habitacion* in Marseille.

To approach such cases, we begin by looking at previous reference studies on houses designed by renowned architects,[1, 5] highlighting the genotype definition of this sample, with a focus on service spaces. Next, we present a socioeconomic and political panorama of the referred housing complexes.

Following we discuss the spatial relationship of service spaces in the three cases through axial, convex and visibility maps, as well as justified graphs and isovists. Finally, we define the genotypes detected in the housing complexes and reach some conclusions.

Genotypes of Domestic Spaces Based on Previous Studies

The relationship between social constructions and the spatial configuration of dwellings is investigated in four influential cases: House at Pregassona by Mario Botta—1979, Giovannitti House by Richard Meier—1967, Diamond House 'A' by John Hejduk—1962 and the Muller House, by Adolf Loos—1929 (Figure 05.1)[5]. All four projects present similarities, which allowed the analysis on the "relationship between concepts of design composition and configuration of architectural space in the domestic interior"[5].

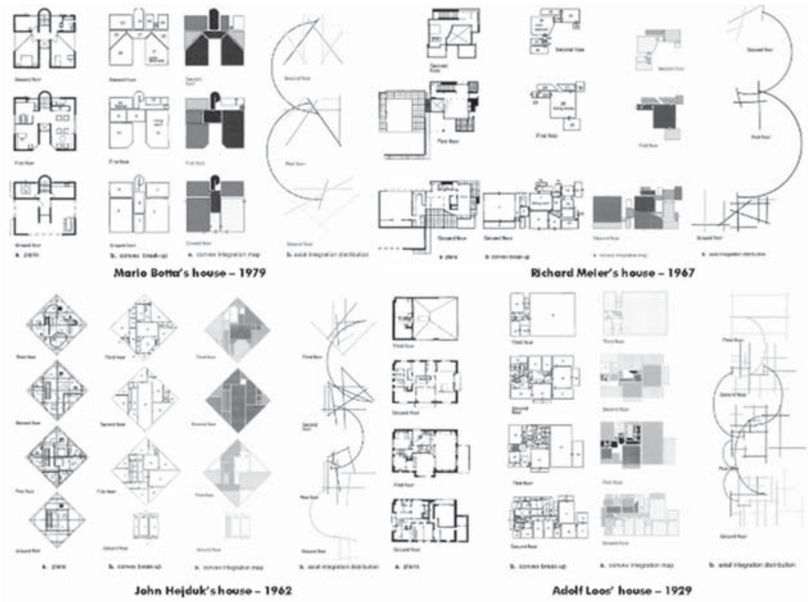

Figure 05.1

Syntactic analysis of four houses[5] (edited by author).

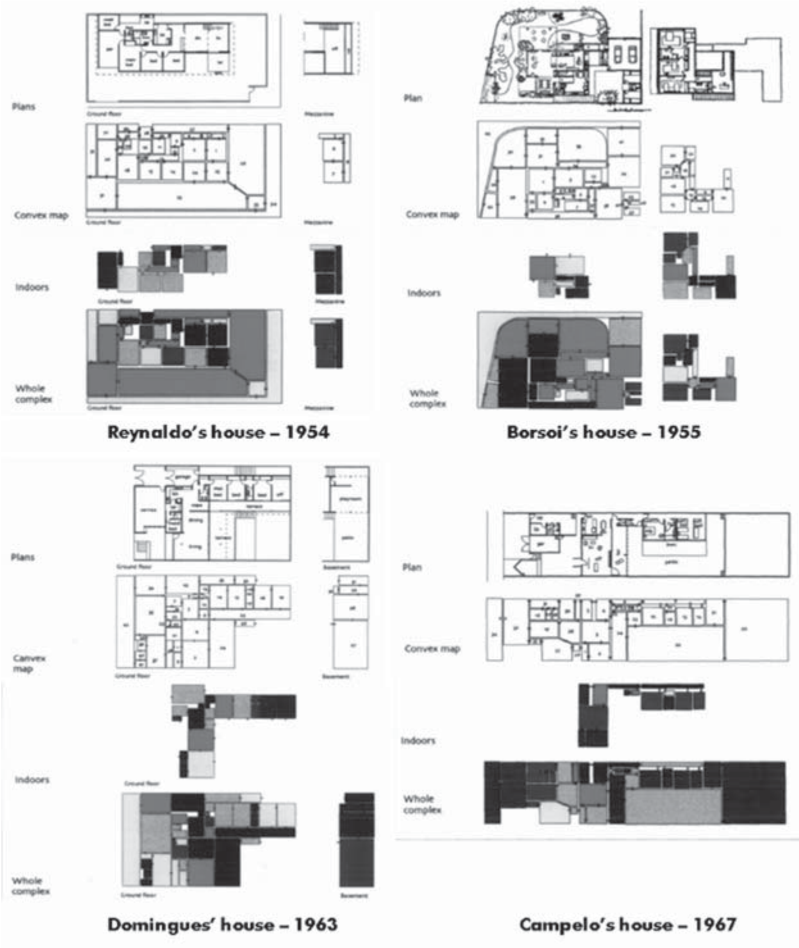

Figure 05.2

Syntactic analysis of modern houses[1] (edited by author).

The spatial relationship between the sectors of modernist housing in Pernambuco and the morphology of domestic spaces was analysed.[1] In the present work, we will examine the houses of four architects studied by the author: Augusto Reynaldo (1954), Acácio Gil Borsoi (1955), Marcos Domingues (1963), and Glauco Campelo (1967) (Figure 05.2).

In Search of a Genotype

Genotype can be defined "in terms of relational and configurational consistencies which show themselves under different phenotypical arrangements".[6] The analysis of rank order of space integration (Table 05.1) revealed that in Brazilian households, the maid's bedroom is the most segregated environment of the system and the living and dining rooms alternate as the most integrated space. Only 25% of the entire sample has the kitchen as the most integrated space of the system. These data reinforce the separation of employees and women—who at the time did not represent a high percentage of Brazil's formal workforce—from other spaces in the house.

House	Rank order of space integration	Rank Order of sector's Integration	Genotype	Total (%)
Botta	L>Mb>D>K>Ld>O	S>P>Se>O	S>Se>P	62,5
Meier	O>L>D>Ld>K>Mb	S>P>Se>O		
Hedjuk	L>D>K>Mb>O	O>S>Se>P		
Loos	K>D>L>Mb>O	S>Se>P>O		
Domingues	D>Ld>L>Mb>K>Mdb>O	S>Se>P>O	S>P>Se	25
Reynaldo	L>D>K=O>Ld>Mdb>Mb	S>Se=O>P		
Borsoi	D>L>Mb>K>Ld>O>Mdb	S>Se>P>O		
Campelo	D>K>L>Ld>Mb>O>Mdb	Se>S>P>O		

L: Living; D: Dinning; K: Kitchen; O: Outside
Mb: Main bedroom; Ld: Laundry; Mdb: Maid's bedroom; S: Social
Se: Service; P: Private

Table 05.1

The houses genotype (by author based on[1, 5]).

Based on the methodology, these genotypes were identified by isolating three sectors of the houses: social, service, and private. The results showed the existence of two distinct types of genotypes, leading to the idea that the social sector is the most accessible in the whole sample, and in 25% of cases the service sector is the most segregated. Even if inserted in different scenarios at the time and place of their designs, these residences reinforce patriarchy's influence in societies and how hierarchy tends to be defined per class, race, and gender. The question that arises from this analysis is whether this logic of modernist design of spaces was different in social housing projects with collective systems of domestic services.

Housing for Gender Equality

Narkomfin's Case

To consolidate the USSR, the reforms of daily life were based on industrialisation through the new model of land occupation, which aimed to solve the housing deficit.[11] The State sponsored a set of standardisation studies of new dwellings for the proletariat, analysing dimensions of traditional kitchens, which resulted in the design of two new typologies: rationalised kitchen and kitchen niche (Figure 05.3).

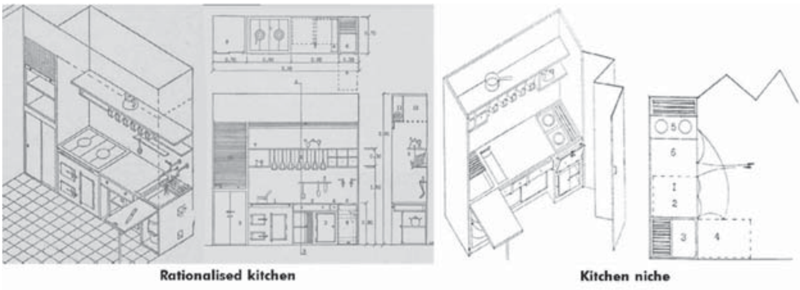

Figure 05.3

Kitchens typologies[11] (pp.194–196, edited by author).

The Narkomfin complex, by Moisei Ginzburg (1928), aimed to materialise the new dwellings model developed by the Soviet state, containing three volumes: residential, community and service (Figure 05.4). The residential component included two types of units: the larger two-storeyed cells "D" with the rationalised kitchen model, and the three-storeyed "F" cells with the kitchen niche integrated the living room (Figure 05.5 and 05.6). Directly connected to the residential building, the community centre housed collective living spaces: rest room, dining room and library. Parallel and 30 meters away from the residential block, the service building housed the collective laundry and guest's houses (Figure 05.6).

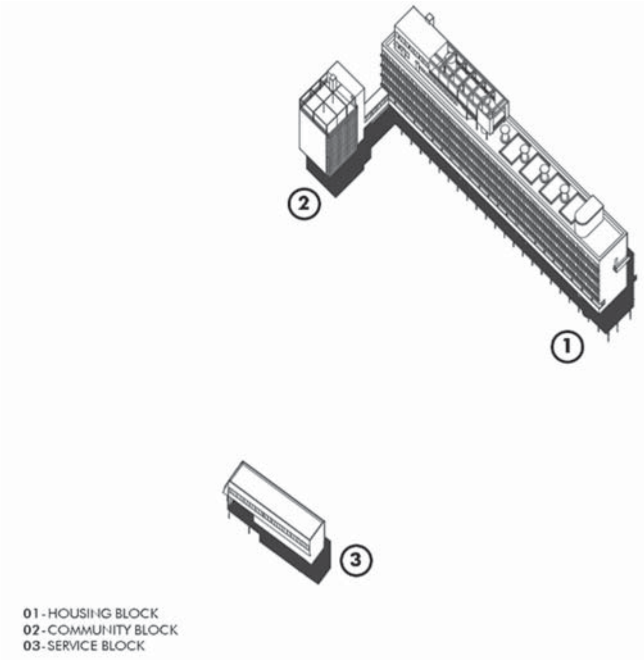

Figure 05.4

Narkomfin site plan[11] (edited by author).

Figure 05.5

Interior of cell typologies “D” and “F”[10] (edited by author).

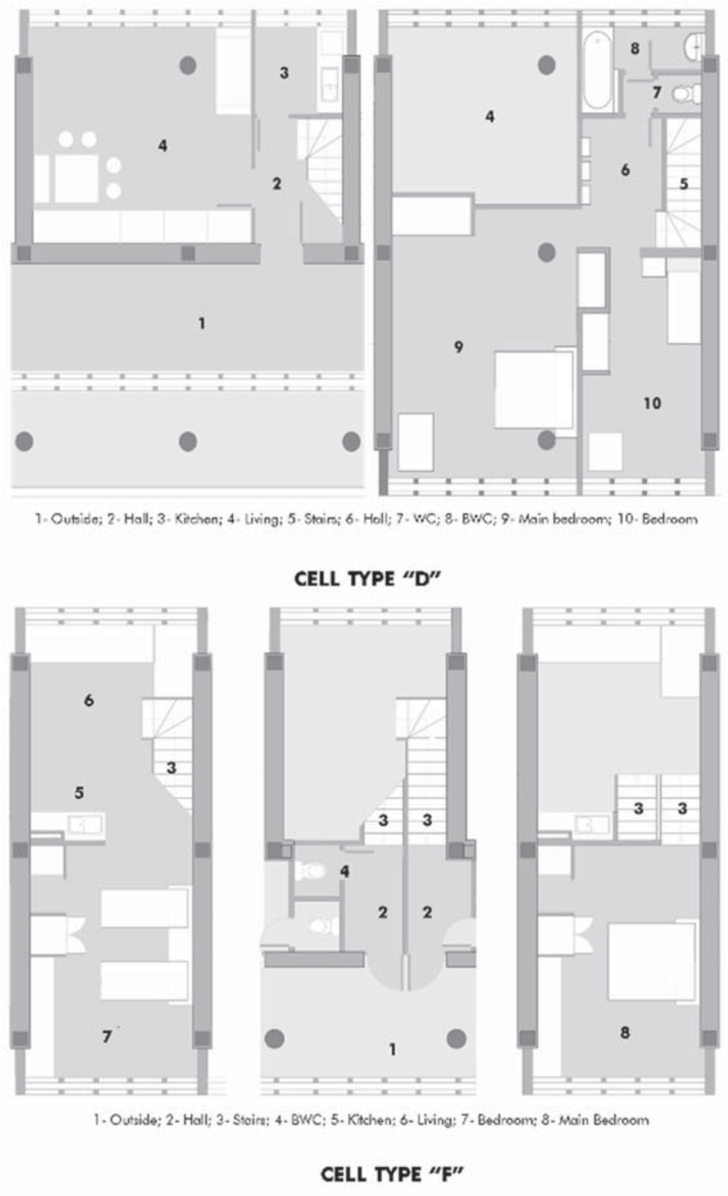

Figure 05.6

Narkomfin "D" and "F" cell typologies[11] (edited by author).

Unité d'Habitation *in Marseille*

Starting in 1945 the French government began to encourage social housing programs that sought to solve the housing deficit. At the core of this discussion, Le Corbusier was a key-figure, presenting several proposals and an extensive theoretical production. The *Unité d'Habitation* in Marseille is considered a synthesis of his studies: the architect pioneeringly introduced the Modulor in all construction stages of this project. The sexism present in his theory and in the Modulor "is not an accident nor a cultural habit result, it was a concept thought, studied and supported in the masculine Renaissance prototype and the idea that it represents humanity."[2]

Corbusier's project was thought as a self-sufficient vertical city. It consisted of a set of modules of different apartment typologies, organised with interior service streets housing from collective laundry, child day care and restaurant, to social spaces, such as the rooftop club (Figure 05.7). In the "E2", the most recurrent typology, kitchen and dining room were integrated as one single large living space (Figure 05.8).

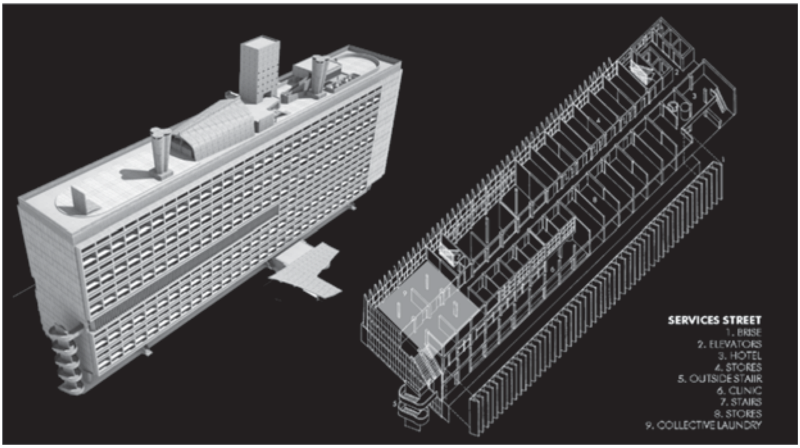

Figure 05.7

Functional division of *Unité d'habitation* in Marseille[8] (edited by author).

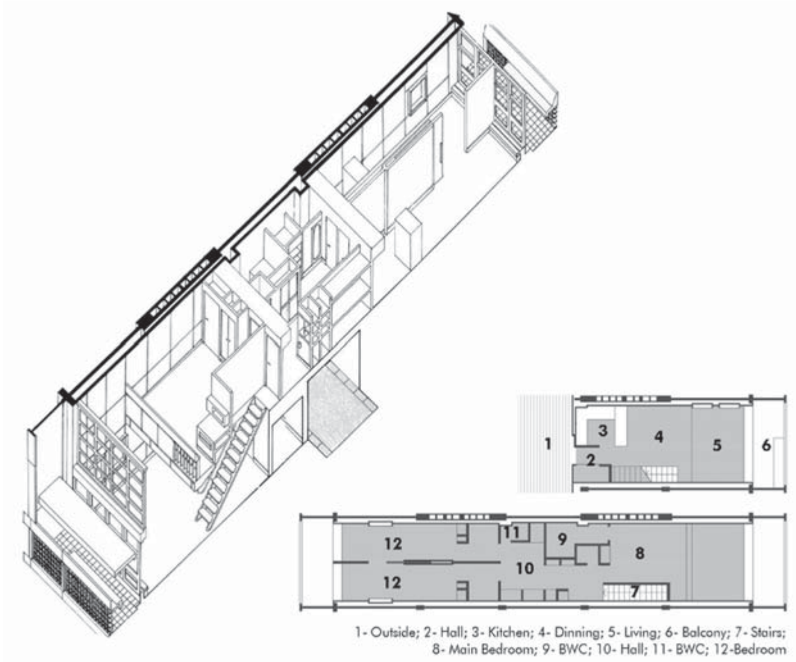

Figure 05.8

Cell type "E2" of *Unité d'habitation* in Marseille[8] (edited by author).

Mendes de Moraes Complex (Pedregulho)

The Department of Popular Housing (DPH) in Rio de Janeiro, Brazil's capital at the time was created in 1946, bringing the housing crisis up to discussion from the collective perspective. Under the leadership of architect Carmen Portinho, DPH issued a design proposal based on the construction of autonomous residential complexes throughout the city.[9] Influenced by modernism, Portinho affirmed the importance of eliminating the unnecessary individual dwelling spaces, such as laundry, favouring the establishment of less unequal gender relations.

The Mendes de Moraes project by Afonso Reidy and Carmen Portinho was based on the Athens Charter and modernist concepts. Three residential volumes conformed the site (main block "A" and secondary blocks "B1" and "B2"), as well as collective equipment: health station, laundry and cooperative, primary school, gymnasium, and swimming pool (Figure

05.9). In this research we will analyse only the residential typologies of block “A”, cells “Q” and “D”. “Q” cells were considered minimal dwellings, featuring only one bedroom connected to the living room. The two-storeyed “D” cells had two bedrooms, kitchen accessed through a hall and stairs leading to the bedrooms (Figure 05.10).

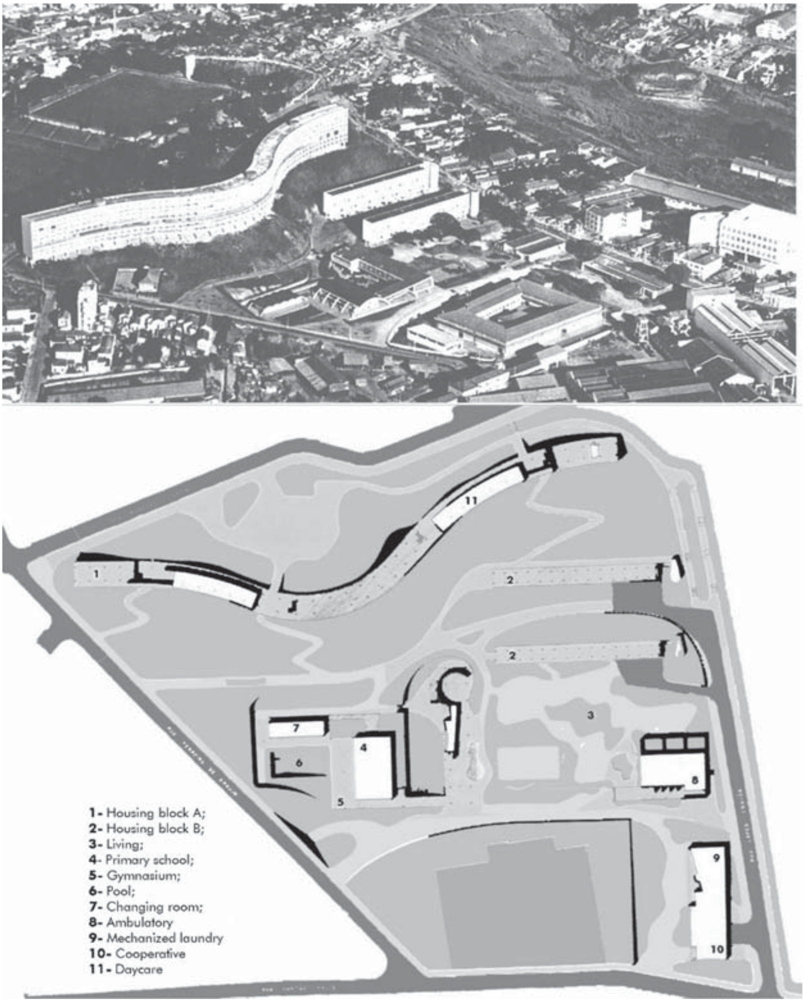

Figure 05.9

Pedregulho site plan[3] (edited by author).

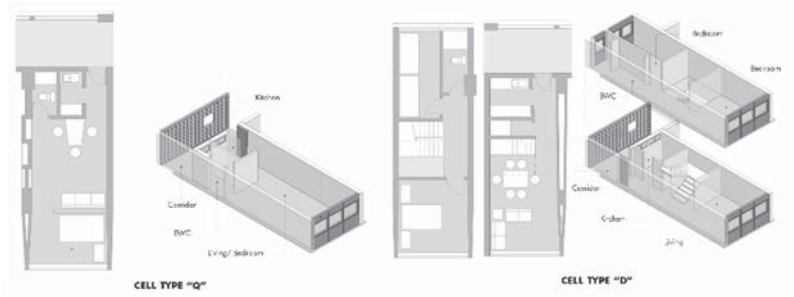

Figure 05.10

Pedregulho cell typologies “Q” and “D”[9] (edited by author).

Discourse and Design Practices in the Housing Complexes

Although domestic activities were already considered a type of work at the time of the three projects, both the State and the architects underestimated the difficulties in altering the social constructions of gender. When the Narkomfin was completed in 1932 the concepts of community life and female freedom had been forgotten, as these had become negative labels of left-wing ideals.[4] As a reflection, the studies of proletariat housing units were only interested in the possibility of standardisation. A very similar scenario occurred in the *Unité d’habitation*, where the need to build a self-sufficient structure seems to have overlapped social issues and those related to gender inequalities, with its collective laundry closing shortly after construction was completed, in 1955, due to the lack of connection with the other service spaces, such as ambulatory and a kindergarten. In the Pedregulho complex we believe there was a more thorough concern towards generating collective equipment that would, in fact, facilitate accomplishing domestic tasks. This finding can be verified through design and socioeconomic justifications given by Carmen Portinho, in which she reiterates the benefits of this equipment on family life and working women. However, we argue that this position was not sustained when it came to the housing units themselves, which continued to reproduce spaces guided by patriarchy. These issues will be further discussed in the morphology-based analysis we will present next.

Morphology of Social Housing

According to the Space Syntax theory[6] people move in axial lines, interact in convex spaces, and see visual fields that change as they move through built environments.[7] Using graph theory to describe configurations allows for investigating the correlation between space configuration and social behaviour.

In this study, we perform comparative analysis of domestic spaces both in the scale of the complex and that of the residential unit, addressing the following analytical variables: integration, symmetry, distributivity, depth, and connectivity. Through the rank order of integration of the housing sectors[1] we sought to trace a common genotype, which corresponds to a set of characteristics intrinsic to the morphology of the objects analysed.

Means and Methods

Criteria for analysing service spaces in the scale of the complex:

First, we should note that we considered the location of columns in the spatial decomposition of the dwellings in regard to the network of permeabilities, as they constituted barriers that influenced the number and shape of convex spaces. The base for axial maps was the exterior access to the collective laundries to revel the interaction between the remaining blocks' access. The graphs of visibility were based on the laundry's washing area and the visual information analysis considered partial isovists cantered is each space, at 180°. The areas and shape of each isovist were also verified, as well as the permanence of visual information space, during the users' movement. All maps generated using the DepthmapX software.

Criteria for analysing service spaces in the scale of the housing unit:

To define the housing typologies sample, which includes five distinct cells, three criteria were followed: *i*) higher incidence; *ii*) availability of existing information; *iii*) location in the main residential blocks. In the process of spatial decomposition and definition of permeability network, we included columns and fixed furniture. Axial and visibility (by connectivity) maps were restricted to the level where the kitchen was located. The justified graph of each cell was generated having the access corridor as the base node, and were elaborated using JASS software, post-edited with AutoCAD. DepthmapX was used for convex, axial and visibility maps, and 180° isovists were employed to analyse the kitchen in each cell. Based on the relationship between the kitchen and the other spaces, the analysis was performed according to integration (RRA), depth, distributivity, symmetry and connectivity.

Analysis and Results

Service spaces in the scale of the complex:

The number of convex spaces varies according to privacy levels, so common spaces, such as the *pilotis* located on the ground floor, connecting corridors and collective equipment, have more convex spaces when compared to dwellings. This finding is explained by the structure that segments the circulation, functioning as barriers in collective spaces (Figure 05.11). In Narkomfin's convex maps the corridors in the residential and community blocks are the most integrated of the complex. Similarly, the convexity analyses of the *Unité d'Habitation* and Pedregulho point to the main circulation areas as the most integrated spaces. This morphology reveals the control of the access to the housing units and the lack of connection between service and leisure/social gathering spaces.

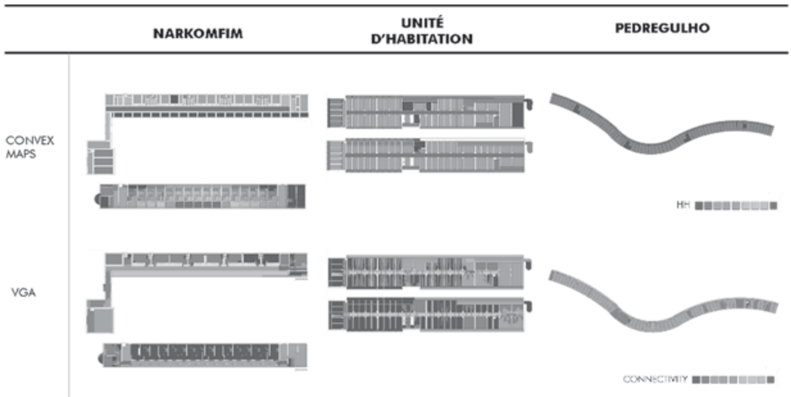

Figure 05.11

Convex and visibility maps of typical access floor plans of social housing complexes (by author based on[11, 8, 9]).

The axial analysis shows that, from the perspective of the inhabitants, physical continuity of the ground floor of the three complexes occurs primarily in convivial spaces, such as *pilotis* and residual areas (Figure 05.11). At Narkomfin, the most integrated spaces are located in the accesses to residential and community blocks, revealing the discontinuity of the service block, which perhaps can be explained by the metric distance between blocks within the lot. In the Pedregulho complex, the axial map reveals that convivial environments are so connected to the educational equipment that the lines have become blurs. Despite this integration, one can notice the discontinuity between the service block and the other components. The axial analysis of the *Unité d'Habitation*, despite its distinct design solution (one single block), shows similar results, with the most integrated spaces being the access corridors in the commercial streets, and the collective laundry being segregated from the other spaces.

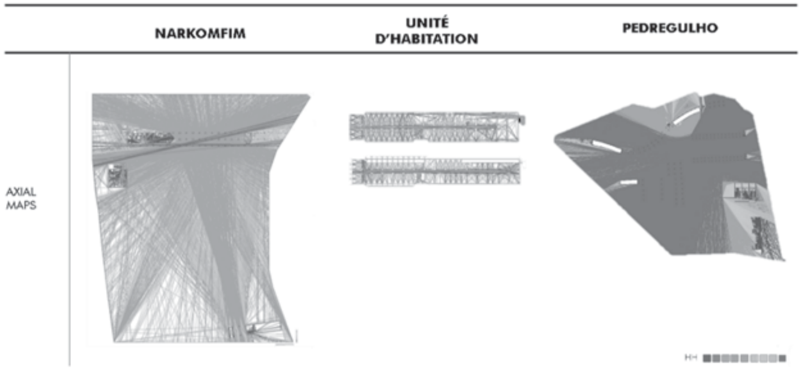

Figure 05.12

Ground floor axial maps of social housing complexes (by author based on[11, 8, 9]).

The analysis of the interior of the collective laundries revealed that the morphology of these spaces shows a satisfactory integration, presenting numerous possibilities of interaction amongst users (Figure 05.12). In this sense, the convex analysis of the Narkomfin laundry reveals few convex spaces, with the entry hall being the most integrated space in the system. Similarly, Pedregulho's collective laundry has few convex spaces, where barriers are constituted by the structure, and the access space is the most integrated within the system. In the collective laundry at *Unité d'Habitation*, the absence of connections affects the network of permeabilities, presenting a single exit and access route to each space. By relating the visibility and isovists maps of each collective laundry, the results reinforce the convexity characteristics, in which the most integrated and connected spaces are those located near the accesses or the largest convex spaces. The convex shape of the isovists allow for little visual information to be lost while visitors move (Figure 05.13).

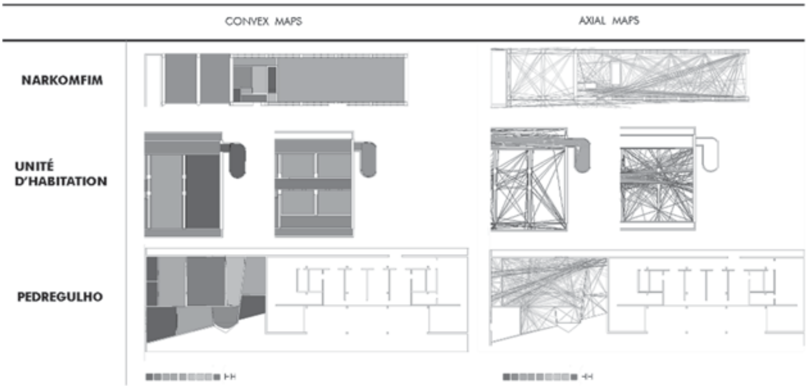

Figure 05.13

Convex and axial maps of collective laundries (by author based on[11, 8, 9]).

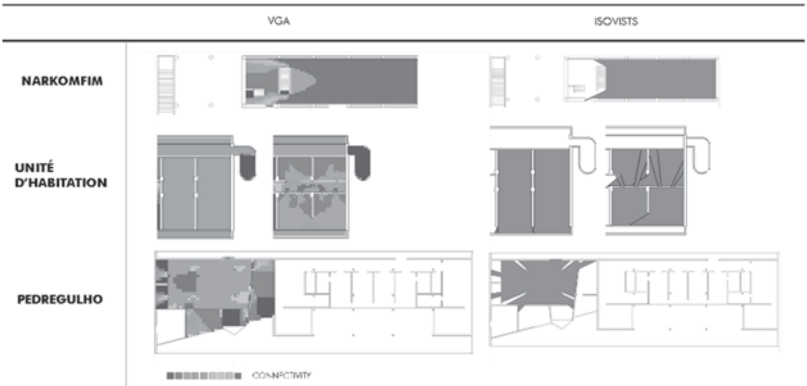

Figure 05.14

Visibility and isovists maps of collective laundries (by author based on[11, 8, 9]).

Service spaces in the scale of the housing unit:

The convex analysis of housing cells shows that the most integrated spaces belong to the social sector (Figure 05.14). 80% of the sample illustrate that kitchens constitute segregated spaces compared to other dwelling spaces. This network of permeability reveals the existence of access restrictions to the service sector, in comparison with the permissions presented by the social sector, findings that are evidenced in the axial analysis.

Narkonfin's axial maps of "D" and "F" cells present visual and physical continuity with social environments, as opposed to the segregated kitchen. As in the Narkomfin, the axial analyses of "Q" and "D" cells in Pedregulho seems to induce a greater interaction and movement in living spaces when compared to kitchens. In contrast, in Unité's "E2" cell both social and service spaces present visual and physical continuity. This finding reveals that morphology of the cell induces a change of spatial unity in the service sector, reinforcing the scenario found in collective laundries in these complexes. Therefore, considering these conditions of accessibility and use of kitchens, we can affirm that the construction of the cognitive space is directly influenced by the social constructions of gender relations, class and race (Figure 05.15).

Figure 05.15

Convex maps of cell typologies of social housing complexes (by author based on[11, 8, 9]).

The analysis of the depth of each cell in relation to the exterior indicates that the deeper systems are those that have larger geometric areas, which were destined to more affluent families. 80% of all typologies analysed show that the kitchen is at the same depth level as the living room (Figure 05.16), revealing that these spatialities exhibit equivalent levels of access control to the social and service sector, as well as, reinforcing the idea that they are a result of functional, political, and socioeconomic needs of each locality.

The integration analysis of each typology, related to convex maps, reveals that the most integrated sector is the one presenting the greatest number of convex spaces, affected greatly by columns and fixed furniture (Table 05.2 and 05.3).

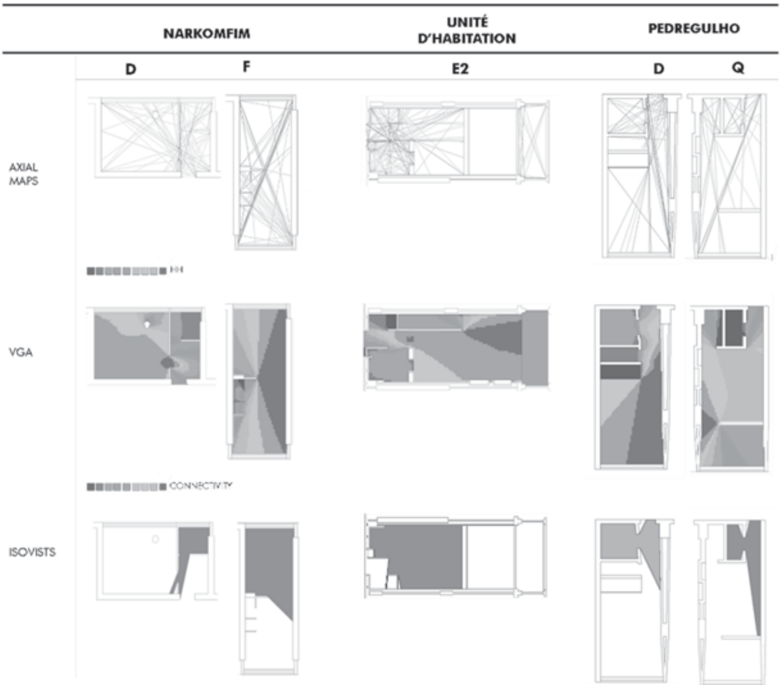

Figure 05.16

Axial, visibility, and isovists maps of cell typologies of social housing complexes (by author based on[11, 8, 9]).

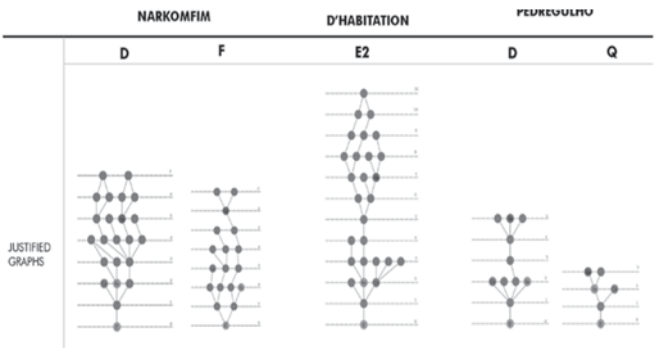

Figure 05.17

Justified graphs of cell typologies of social housing complexes (by author based on[11, 8, 9]).

	Narkomfin		Unité d'habitation in Marseille	Pedregulho	
Author	Moisei Ginzburg		Le Corbusier	Afonso Reidy e Carmen Portinho	
Year Built	1928		1947	1946	
Localization	Moscow		Marseille	Rio de Janeiro	
Cells type	**D**	**F**	**E2**	**Q**	**D**
Area (m^2)	85.30	60.00	118.00	22.30	58.50
Convex spaces	23	18	28	6	11
Depth	7	7	11	3	5
Integration (RRA)	1,431	2,148	1,854	1,337	1,411
Type of graph	3	2	2	1	1
Distributivity	1,090	0,157	0,647	0	0,222
Symmetry	0,352	1,210	0,437	4,000	1,753

1: Tree-like configuration 2: Tree-like configuration with ring on social sector 3: Tree-like configuration with ring on both sectors, social and private

Table 05.2

Social housing complexes: general data (by author based on[11, 8, 9]).

In 80% of the cases the kitchen proved to be equally integrated into the living space systems. This data indicates that the morphology of these cells should favour intense and informal use of the living and service spaces. However, by relating integration values to visibility maps, it is observed that the more integrated and visually connected spaces remain only in the social sector.

	Narkomfin		Unité d'habitation in Marseille	Pedregulho	
	D	F	E2	Q	D
Main spaces	Area (m²)				
L	22.90	15.50	29.35	10.40	12.40
K	3.75	1.40	4.85	1.80	3.00
Mb	23.23	16.50	21.60	6.00	9.60
O	-	-	-	-	-
Main spaces	Depth				
L	1	3	2	2	2
K	1	4	2	2	2
Mb	5	7	7	3	5
O	-	-	-	-	-
Main spaces	Integration (RRA)				
L	1,757	2,995	1,562	1,719	1,582
K	1,489	1,735	1,893	1,719	1,582
Mb	1,391	2,107	1,832	1,719	1,809
O	1,489	1,425	1,984	0,573	1,582
Main spaces	Space type				
L	c	c	c	b	a
K	a	a	b	a	a
Mb	c	b	b	a	a
O	a	b	a	a	a
Main spaces	Distributivity				
L	D	D	D	ND	ND
K	ND	ND	ND	ND	ND
Mb	D	ND	ND	ND	ND
O	ND	ND	ND	ND	ND
Main spaces	Space connectivity				
L	3	3	3	3	1
K	1	1	4	3	1
Mb	3	2	3	1	1
O	1	2	1	1	1

L: Living Mb: Main bedroom K: Kitchen O: Outside
D: Distributive ND: Non-distributive

Table 05.3

Social housing complexes: syntactic data of cells main space (by author based on[11, 8, 9]).

By relating the partial isovists and the space typologies of kitchens, t80% of the isovists have a pointed shape, that allows the visual information to be easily lost. Thus, by comparing the measures of distributivity, symmetry, and the space typologies of kitchen, it is evident that the morphology of these cells reinforces the sexist aspects of society, precisely due to the inaccessibility and absence of connections. Based on the assumption that women have always been exclusively responsible for performing domestic activities, these spatialities generate a scenario that does not allow for the existence of new social interactions, inducing the perpetuation of the gender's role.

Genotype of the Housing Cells

The morphologies of the cells we studied express the polarisation of living spaces and spaces dedicated to performing household activities. Thus, the living space, which composes the social sector, is always more permeable when compared to the kitchen, which composes the service sector. According to methodology[1], isolating the three sectors of a house (social, service and private) in the rank order of integration allowed to defining genotypes of housing typologies.

The results of our research did not indicate the existence of a common genotype, since each typology presents its own set of primary information (Table 05.4). However, there are similarities in the position occupied by the service sector in the rank order of the integration sector, where in 40% of the sample this sector remains in second position, while the social sector is the most integrated within the systems. In parallel, 20% of the sample shows the service sector as the most integrated. When we relate the results to the genotypes found in the previous studies,[1, 5] 20% of our sample has the genotype identical to the houses analysed in these two studies, in which the service sector is the most segregated in the system (Table 05.1).

	Cells type	Rank Order of space Integration	Rank Order of sector's Integration	Genotype	Total (%)
Narkomfin	**D**	Mb<O=K<L	P<O=Se<S	P<Se<S	20
	F	O<K<Mb<L	O<Se<P<S	Se<P<S	20
Unité d'habitation in Marseille	**E2**	L<Mb<K<O	S<P<Se<O	S>P>Se	20
Pedregulho	**Q**	O<K=Mb=L	S<Se=P=O	S>Se=P	20
	D	O=K=L<Mb	O=S=Se<P	S=Se<P	20

L: Living; Mb: Main bedroom; K: Kitchen; O: Outside
P: Private; S: Social; Se: Service

Table 05.4

Social housing complexes genotype.

Having said this, we need to clarify that, in addition to the different programmatic contents of the dwellings analysed[1, 5] and the three social housing complexes we present here, the economic realities also differ from each other: the single-family homes belonged mostly to middle class clients, while the housing complexes were designed for the working class, which, in addition, involved the optimisation of the interior space of the unit and presented common living and service spaces that were suppressed from the individual units.

These findings lead to two questions, which remain open at this stage of the research: Would the divergence of genotypes between ours and the sample analysed by the referred authors be justified by the different contexts the designs occurred in, even though some of these houses followed similar modernist ideals? Is the number of typologies analysed here insufficient to determine a single common genotype?

Conclusions

Guided by an analytical approach, the present discussion sought to show aspects related to how the domestic space affect the perpetuation of gender roles, addressing this influence in three emblematic modernist social housing complexes: the Narkomfin, in Russia, the *Unité d'Habitation* of Marseille, in France, and the Pedregulho complex, in Brazil. Assuming the plural scenario that characterises modernism and its socioeconomic and political realities, this analysis was based on the investigation of the correspondence between the morphology of residential units in the three cases and their relations with the women liberation discourses against being considered the sole responsible for accomplishing domestic activities.

Initially we had suspected that the spatial structures of housing complexes containing collective spaces for domestic services would present characteristics distinct from those found in single-family houses designed for middle and upper classes analysed in the previous studies[1, 5] where these types of space are generally segregated at deeper levels of their spatial systems. However, it was found that, although the modern movement supported the idea of housing as a tool for social transformation, the design strategies of both these single-family homes and the social housing complexes we studied) tended to reproduce earlier design forms, highlighting the influence of patriarchal societies over domestic spaces.

This perspective, however preliminary—as the sample should for sure involve more examples—reinforces the morphological analysis as an important tool for understanding spatial relations in architecture. Thus, the syntactic study of the individual and collective service spaces of housing complexes revealed very relevant characteristics of the sample defined in this study. In addition, it was necessary to highlight the specificities of each case to corroborate in the process of understanding the architectural strategies that reinforce sexism in the design of the social housing complexes. Through our studies, it was evidenced that gender relations directly influence the morphology of domestic spaces and that, overall, the spatial structures we studied reinforce and perpetuate gender stereotypes.

References

1. Amorim, Luiz Manuel do Eirado. The Sectors' Paradigm: a study of the spatial and functional nature of modernist housing in Northeast, Brazil. 1999. 438 f. Thesis (PhD Advanced Architectural Studies): The Bartlett School of Graduate Studies, University College of London, Londres, 1999.
2. Antunes, Lia Pereira Saraiva Gil. Arquitectura: substantivo feminino: contribuição para uma história das mulheres na arquitectura. Dissertação (Mestrado Integrado em Arquitetura)—Universidade de Coimbra, Coimbra, 2012.
3. Bonduki, Nabil (Org.). Affonso Eduardo Reidy. Lisboa: Editorial Blau, 2000.
4. Carini, Martha Claudia. Gender equality within the home: a feminist approach to the elimination of the domestic labour. Cambridge: Cambridge University, 2016.
5. Hanson, Juliane. Decoding homes and houses. Cambridge University Press, Cambridge, 1998.
6. Hillier, Hanson and Graham. Ideas are in things: An application of the space syntax method to discovering house genotypes. Environment and Planning B: Planning and Design 14, 363–385, 1987.
7. Hillier, B., and Vaughan, L. The city as one thing. In Progress in Planning, Vol. 67, 2007.
8. Sbriglio, Jacques. Le Corbusier: the unité d'habitacion in Marseilles. Basel: Birkhäuser, 2003.
9. Silva, Helga Santos da. Arquitetura moderna para habitação popular: a apropriação dos espaços no conjunto residencial Mendes de Moraes (Pedregulho). Dissertação. Universidade Federal do Rio de Janeiro, Rio de Janeiro, 2006.
10. Spinelli, Melikova. The Constructivist Project. NARKOMFIN—A web documentary. Moscow, 2013.

11. Vega, Daniel Movilla. Vivienda y Revolución.El Concurso entre Camaradas de la OSA, la Sección de Tipificación del Stroykom y la Casa Experimental de Transición Narkomfin (1926-1930). Tese. Universidad Politécnica de Madrid, Madri, 2015.
12. Weisman, Leslie Kanes. Women's Environmental Rights: A Manifesto. In Rendell, Jane. (org.) Penner, Barbara. (org.) Borden, Ian. (org) Gender Space Architecture: An Interdisciplinary Introduction. London: Routledge, 2000.

CHAPTER SIX

THE SPACE BETWEEN THE FORMAL AND THE INFORMAL CITY ALONGSIDE THE RIVER MARANGUAPINHO

CAMILA SANTANA, UGO SANTANA

Fortaleza: A Fragmented City

Fortaleza, with a population of 2,609,716 inhabitants, is a Brazilian city marked by the contrast of planned and unplanned areas, that reflects its social inequities at the urban space. The precarious settlements of the city are mostly located at environmentally degraded areas, such as the River Maranguapinho. The objective of this paper is to analyse how the formal and the informal urban grid connects alongside the margins of the River Maranguapinho and how the spatial configuration affects land use and movement patterns in this area of the city. The study considers as formal city the planned areas, designed following a conceived urban grid, controlled by governmental actions; and as informal city the self-produced space, where the concentration of precarious settlements defines the limits of the public space. The research is based on the analysis of the area located from the river's margins to the beginning of the planned grid of the city, aiming to identify how the formal and informal urban spaces connect. The analysis of the relations between the formal and the informal urban configuration considered the concept of "urbanity", argued by Hillier[1] (p.127), to identify how the grid offers routes to different areas of the city affecting movement and how the public space is structured and used by the inhabitants.

In Fortaleza, the formal urban configuration is marked by the regular grid that shaped most of the blocks. According to Accioly[2] (p.96), this regular configuration is a result of the expansion plans conceived by Silva Paulet, in 1824, implemented by the city administration. These plans show: A) the initial urban occupation, characterized by irregular grid, following the margins of the River Pajeú, located in the neighbourhood called Centro; B) the proposed regular grid to expand the city occupation; C) the definition of expansion vectors, connecting Centro to the east, west and south regions of the city. The expansion of the "formal city" has reproduced this original rectangular grid and followed the defined vectors until the present days.

It is important to note that the years of drought attracted to Fortaleza immigrants from the rural zones of the state of Ceará, promoting the expansion of informal settlements in distant areas of the city, concentrating a new population, without the city administration support. Over the past years, with the city growth in population and in area, the grid has been continuously adapted, as the formal and informal areas coexist, multiplying its effects. As Balbo[3] (p.23) argued, together 'with the carefully planned city, a second one has appeared and developed, rapidly growing larger than the planned one, for all those who cannot afford living in the latter'.

In Fortaleza, the precarious settlements are concentrated (1) at the coast region, nearby the port and alongside River Ceará, at the western side of the city; (2) at the southwestern region of the city, mostly marked by irregular plots; (3) at the margins of the River Maranguapinho and the River Cocó. These informal settlements are classified by the Prefeitura Municipal de Fortaleza (City Administration) documents as: social housing, tenements, slums (favelas), irregular plots and collective effort housing. Figure 06.1 identifies 624 slums. These slums represent the largest area of informal settlements of the city.

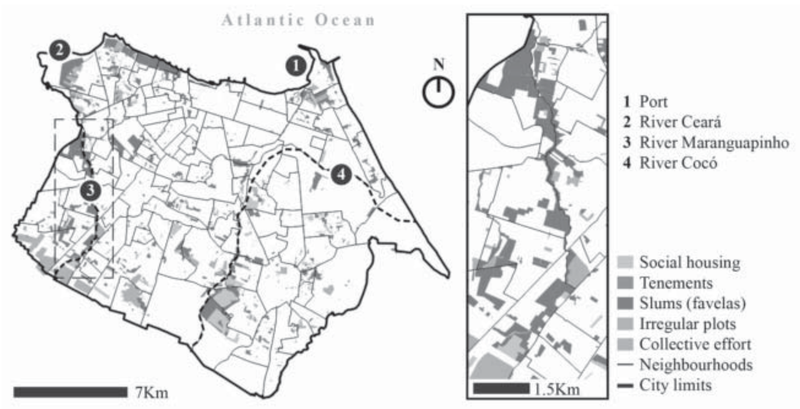

Figure 06.1

Informal Settlements Map based on Prefeitura Municipal de Fortaleza (2017).

This map demonstrates a concentration of precarious settlements in environmentally protected areas of the city. The River Maranguapinho, one of these environmentally protected areas, present precarious settlements alongside its extension. Considering that the governmental actions in these areas aim to regulate the urban expansion, this study raises the question: how these urban interventions that connect the formal and informal grid affect the land use and movement patterns?

Pursuing Fortaleza Spatial Configuration

The research is based on the Space Syntax Theory (Hillier, Hanson, 1984) aiming to relate spatial configuration, location, use and movement patterns in the urban space. The study reflects the analysis of the settlements located nearby the River Maranguapinho's margins and the planned grid of the city, identifying how the formal and informal urban spaces connect. The maps produced by Prefeitura Municipal de Fortaleza (City Administration), that locates and classifies the existent precarious settlements in the city boundaries, were analysed. The municipal government documents associate the maps with information such as: population, urban infrastructure, per capita income and the number of dwellings.

Subsequently, to compare the data collected in the city administration's documents and the morphology of the urban grid, an axial map was created from a linear representation of Fortaleza urban grid elaborated by Ugo Santana (2017) in the QGIS software. Based on the axial map, a segment map, and values of normalised angular integration (NAIN) and choice (NACH) were generated by the Space Syntax Toolkit and the software DepthmapX. The values represent a global scale, involving all segments within Fortaleza boundaries and local scales with radii of 400, 800, 1200, 1600 and 2400 meters. The values obtained by the software were then compared to spatial characteristics of the urban grid identified by formal and informal configuration.

Integration represents the topologic distance from a segment to all others in the system. The spaces that present higher integration values are those with the smaller topologic distance from all other spaces. Choice represents the most probable routes between two points in the system. While integration is associated with the identification of centralities, high values of choice enlighten a grid that represents the main routes of movement in the city[1].

The segment map created was overlaid to the precarious settlements map aiming to identify relations between the spatial configuration and the settlements location. Based on the study of the integration and choice values it was possible to analyse the relations between the formal and the informal settlements in the spatial structure of Fortaleza's urban grid. Once the grid structure is responsible for the majority of the variations in the movement density, the configuration of the formal and the informal settlements represents a fundamental aspect of the urban space analysis.[1]

The Fragmented Grid at Global Scale

The segment map of Fortaleza (Figure 06.2), at global scale, displays that the areas with higher integration values are located at Centro—where the city occupation began—and the nearby neighbourhoods, represented in red lines. Besides that, there are other areas of high integration values towards the southern region, near the geometric centre of the city, following one of its expansion vectors. However, there are some factors that limit the connections between this main highly integrated core and the other regions of the city. For this reason, there is a gradual reduction of integration values in most streets of the city, represented in green lines at the segment map. The map also shows in blue lines the most segregated streets of the system, mainly located at the city limits.

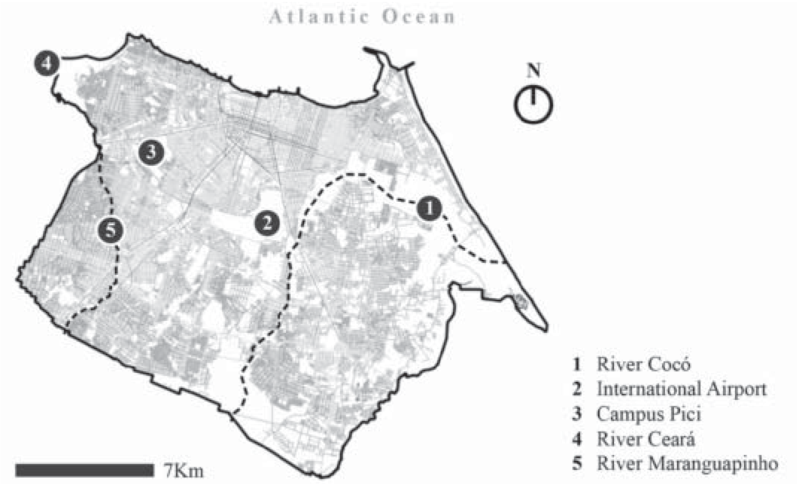

Figure 06.2

Factors of restrain of the integration core—Integration (NAIN), global scale.

The main factors that restrain the growth of this highly integrated core are: (1) the River Cocó, (2) the International Airport Pinto Martins and (3) the Campus Pici of the Federal University of Ceará. Alongside the River Cocó there are large empty spaces among the roads that connects the eastern and the southern regions, creating islands and clearly separating the integrated core of the city from other regions. The Airport and the Campus Pici limit the integration values (Figure 06.2). The International Airport, together with the Airforce Base, creates an empty space at the geometrical centre of the city. The Campus Pici—located between the Airport and the western border of the city, where River Ceará passes—prevents the establishment of new roads, reducing the integration values in this area. The River Ceará and its main affluent, the River Maranguapinho, also divides this region—represented in yellow lines—from the ones in green lines. The segment map shows the expansion vector that follows General Osório de Paiva Avenue, that starts at Centro and goes between Campus Pici and the International Airport.

The River Maraguapinho

Since 2008, the River Maranguapinho was the object of the government interventions at its margins, but until now they had not been completed, and still presents areas with informal housing. The main urban interventions at the river's margins are concentrated in three areas: (1) between the Avenues Mister Hull and Senador Fernandes Távora, which is partially completed; (2) between the Avenues Senador Fernandes Távora and General Osório de Paiva, which is not completed; (3) between General Osório de Paiva Avenue and the 4o Anel Viário (city limits), which is not completed. The location of the interventions is clearly associated with one of the expansion vectors of the city, the General Osório de Paiva Avenue, that presents higher integration values at global scale, affecting the nearby areas.

The River Maranguapinho passes alongside 10 neighbourhoods (Table 06.1), concentrating 302,675 inhabitants, with areas characterised by pollution, lack of sanitation and informal occupation. Considering the areas located inside the limits of the city, there are 28 slums registered by the Prefeitura Municipal de Fortaleza's documents,[4] with different spatial characteristics. Some of them already present patterns of the formal urban zones, incorporated to the regular road network, by the governmental intervention at the public space. At Table 06.1, it is exposed information of each neighbourhood, such as population; number of dwellings; per capita income; and access to electric energy, water supply and sewer infrastructure.

These data reveal the social inequities at the urban space, in a highly populated area.

Neighbourhood	Population	Dwellings	Per capita income (R$)	Electric energy (%)	Water supply (%)	Sewer (%)
Antônio Bezerra	25,764	7,478	485.21	99,65	89,02	77,47
Genibaú	40,310	11,343	271.81	99,43	97,51	62,88
Autran Nunes	21,198	5,609	288.48	99,66	95,92	84,20
Henrique Jorge	26,965	7,816	476.55	99,78	96,11	26,28
João XXIII	18,341	5,231	386.57	99,83	94,91	45,90
Bonsucesso	41,119	11,740	370.66	99,69	96,11	54,01
Granja Portugal	39,617	10,791	276.38	99,02	97,79	44,35
Bom Jardim	37,699	10,462	291.69	99,46	97,83	41,04
Parque São José	10,474	3,017	358.38	99,77	95,46	19,46
Canindezinho	41,188	11,544	267.41	99,45	98,87	14,92

Table 06.1

Neighbourhood information—Prefeitura Municipal de Fortaleza (2017).

Although some indicators—such as electric energy and water supply—are very similar among the neighbourhoods, showing that the urban infrastructure has permeated the city, other indicators present differences. When the per capita income is exposed at the map (Figure 06.3), it is possible to identify that the River Maranguapinho divides the population with lower income, concentrating them on its western margin. The map below (Figure 06.3) also displays the limited sewer infrastructure, in contradiction with the water supply system data indicated on Table 06.1.

The River presents approximately 11 kilometres of extension inside Fortaleza limits, with 13 crossing passages, marked by bridges. At these crossing passages, there are regions with integration values slightly higher than the spaces between them. Over the years, when a crossing passage was implemented, it promoted a higher integration and subsequently the regulation of the grid in the nearby areas. The less integrated areas, at local scale, are located between the crossing passages, showing that the integration is affected by the inexistence of connections and a larger number of dead-end spaces. These passages also represent the government's actions towards the River Maranguapinho, aiming to expand the formal urban grid.

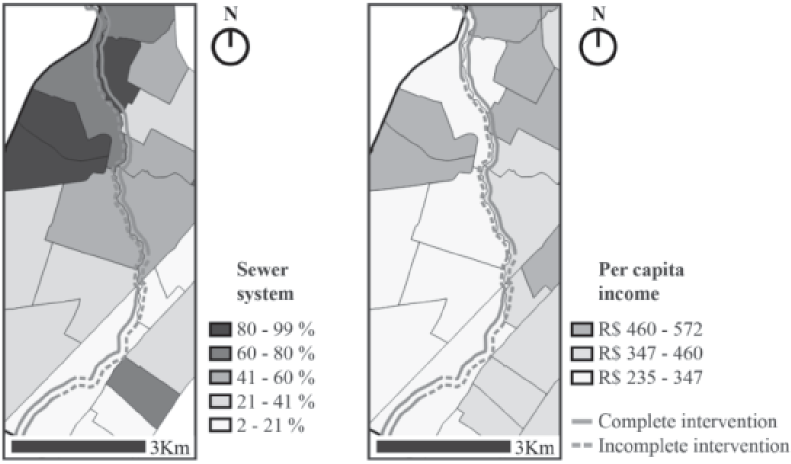

Figure 06. 3

Sewer system and per capita income map based on Prefeitura Municipal de Fortaleza (2017).

It is also observed that around the General Osório de Paiva Avenue the government's actions are more effective than other areas alongside the River, reducing the number of informal areas. The informal settlements are characterised by irregular geometry, great number of dead-end spaces and streets with reduced cross section. Paradoxically, the formal spaces are marked by a great number of connections, by the regularity of the grid and increased cross section of the streets. In a local scale (800 metres), the difference in integration values between the regular and the irregular blocks become clearer. In Fortaleza space configuration, this corresponds to the absence or presence of self-constructed settlements, a counterpoint to the urbanised regions, where the rectangular grid prevails. The areas of the River that present some kind of governmental intervention—marked by housing removal and the construction of marginal roads—in any of its margins have higher integration values, at global and at local scale (800 metres), attracting real estate investments in the neighbourhood.

The regions without any governmental intervention are gradually occupied by self-constructed housing, at environmentally degraded areas with flood and collapse risk, promoting the destruction of the native river-margin vegetation (Figure 06.4). Furthermore, the lack of urban infrastructure generates the river pollution. As self-constructed housing doesn't follow any urban parameter, the public spaces are the result of unoccupied areas, marked by an irregular and limited grid, without the separation between vehicles or pedestrian's movement. The governmental interventions generally start with the removal of part of the dwellings and their inhabitants are relocated to social housing buildings, aiming to expand the urban grid, with the construction of the new streets. These interventions are also structured to contain the occupation towards the river line, separating the river from the informal constructions, trying to physically protect it from degradation. These interventions rarely include the construction of community public spaces to promote co-presence, resulting in empty public spaces at most hours of the day. Although the infrastructure is not completed, these marginal streets are built as continuous movement lanes with stops only at the crossing passages, presenting wider cross-section than the existing streets in the informal settlements.

These urban interventions promote new relations between formal and informal settlements, affecting integration values and choice, through the new possibilities of movement in the city. Villaça[5] argues that the urban space is structured by human movement, considering the work force and consume activities, attracting commercial and services uses, creating diversity and new centralities at local scale. This context changes the value of the land, produced by location, promoting the expansion of the formal areas and the gradual absorption of the informal settlements.

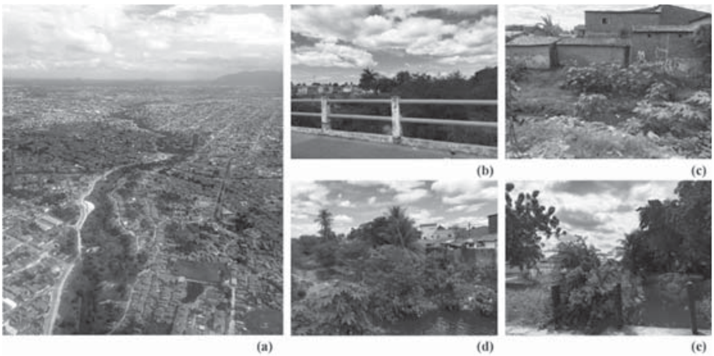

Figure 06.4

(a) Aerial view of precarious settlements on the river's margins: Genibaú, Henrique Jorge and João XXIII neighbourhoods; (b) Osório de Paiva Avenue bridge view; (c) Self-constructed housing at the river's margins at Cônego de Castro Avenue; (d) environmentally degraded areas at Vital Brasil Street and (e) at Emílio de Menezes Street.

One River, Two Cities, Three Samples

The study of the urban structure connected to the river's margins was made by the selection of three Sectors, each one limited at 800 metres radius, as shown in the Figure 06.5. The decision of this radius considered a distance that could surround a city space that contained both formal and informal settlements. This distance can give an idea of the scale of the informal areas. In Sectors 1 and 2 there are urban interventions only on the eastern margin; and on Sector 3 on the western margin. In Sector 1 there is the largest informal settlement, and this occurs because both Sector 2 and 3 are closer to areas with higher integration values in global scale.

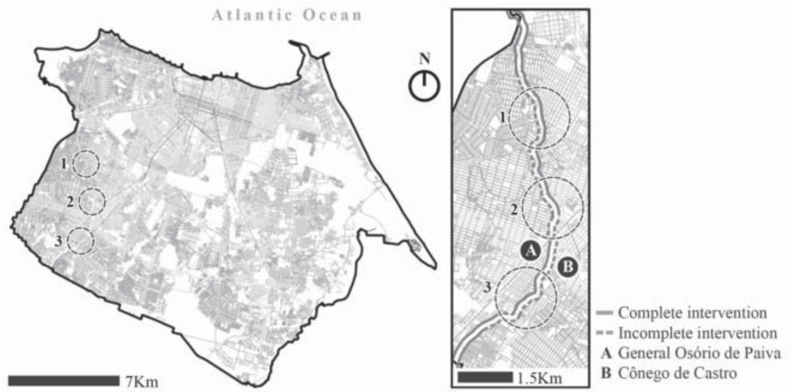

Figure 06.5

Selected Sectors and integration values (NAIN), global scale.

Besides the high integration values, between the Sector 2 and 3 there are areas with high choice values, indicating significant paths in the region in the global scale, as shown in 06.6. General Osório de Paiva Avenue—an important connection between the city centre and Maranguape city, in the southern border—passes alongside Sector 2 and 3, bringing from the central area an important integration vector in the adjacent streets. This Avenue has a high integration value (1.68), close to the system maximum (maximum: 1.89, medium: 1.22, minimum: 1.44), and also a high choice value (1.42), compared to other streets (maximum: 1.61, medium: 0.91, minimum: 0.0) of the system. These values prove the influence of the Avenue to the city. In the Sector 3 exists another street, Cônego de Castro Avenue, also with a high integration value (1.63). It is important to note that both Avenues are mainly occupied by commercial land uses. In this Sector, the presence of these two avenues, increases the integration of all adjacent streets, reducing the difference between formal and informal spaces values. Sector 3 also presents the smaller area of informal spaces.

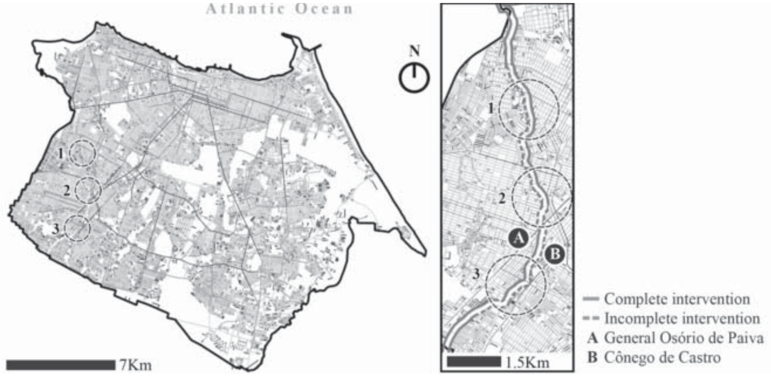

Figure 06.6

Selected Sectors and choice values (NACH), global scale.

The difference in values between formal and informal areas are very clear: the first ones are more integrated than the second ones in most of the cases, as shown in the Figure 06.7. The streets that connect formal and informal spaces, generally present characteristics of both situations: reduced cross section and irregular shape, but also sidewalks and asphalt pavement in some cases. When it is considered the local scales (800m), the difference between the highest and lowest values of integration increases.

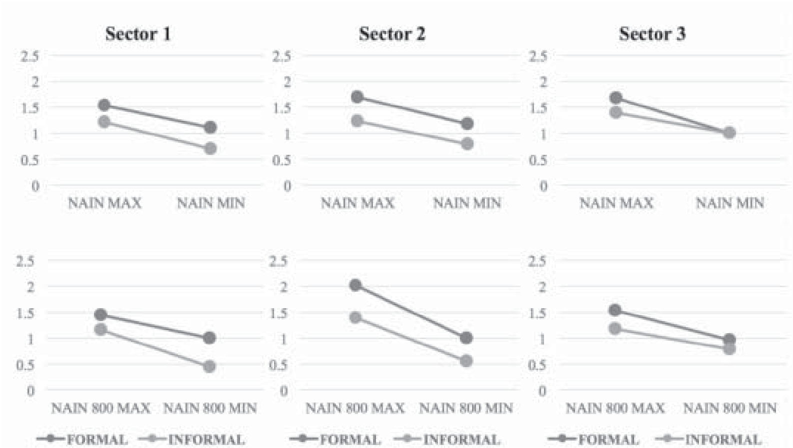

Figure 06.7

Selected Sectors and choice values (NACH), global scale.

In a local scale the movement is facilitated by the rectangular grid, allowing a larger number of paths, and reducing the possibility of dead-end spaces, as shown in Figure 06.8. When the segment map is analysed in local scales, now with radii between 1200 and 1600 metres, it is possible to observe a clear formation of some centralities in both sides of the river; this is different to the global scale, which points to a high integration only in the city centre. Beyond the radius of 2400 metres, Centro becomes the most integrated area of the city.

Integration and choice measures indicate how the public space is organised and how it limits the precarious settlements areas through urban interventions, implemented by municipal and state's government. The urban grid structure also reveals a social distribution in the space, once the precarious settlements generated their own configuration inside an area without formal planning. The irregular shape, with lower integration and choice values, affects the accessibility of the inhabitants and how they relate with the city. In this context, it is possible to observe considerable changes in the syntactic measures when it is analysed the local space, comparing them to areas with the rectangular grid (Figure 06.8).

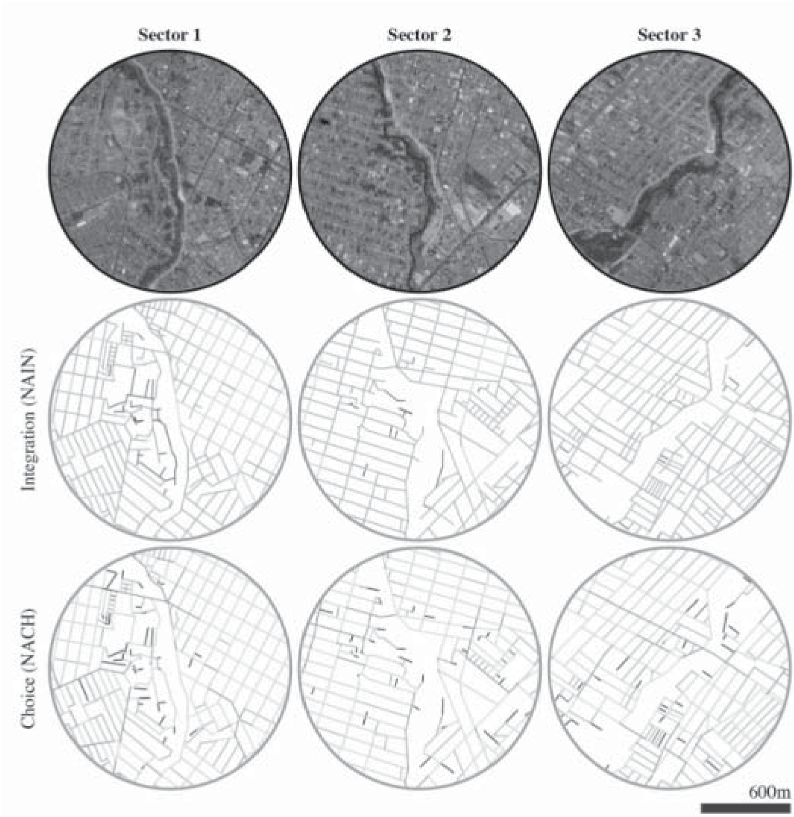

Figure 06.8

Integration (NAIN) and Choice (NACH), local scale (800m).

This study shows that alongside the River Maranguapinho, the formal and informal city coexist, connecting the fragmented spaces to the regular grid in distinct ways. As Balbo[3] (p.27) argues, the existent spatial fragmentation in these self-generated settlements is connected to the rapid expansion of the city; the economic and political aspects; the urban planning regulation and the lack of them; and the role of the state regulating the urban space.

It is possible to identify that after the state's intervention at informal settlements located alongside the River Maranguapinho, the consolidation process has promoted changes in the informal grid, aiming to connect it to the formal city. In this context, it is important to note that the spatial configuration of the urban grid and location can affect the consolidation of informal settlements once it influences the patterns of movement and land use.[10] Although this region still presents a large number of self-produced settlements, some parts of the informal grid became legally recognised and consolidated through the years, with access to the urban infrastructure and services.[14]

Conclusions

During this study, when the city urban grid was analysed in both axial and segment maps and compared to the maps produced by Prefeitura Municipal de Fortaleza,[4] it was observed that the segment map better reflected the differences between the spatial configuration of the formal and the informal settlements, at local scale. The analysed Sectors present different levels of accessibility. The integration and choice measures at global scale affect the inhabitant's movement at local scale, creating segregated areas, especially in larger precarious settlements.

The study shows that the informal grid in this area was once generated by precarious settlements, that mostly follows the river line. The public space is restricted and unplanned, without the separation between pedestrians' and vehicles' space, and without open spaces. This context is caused by the expansion of self-produced buildings with small built area, once the primary need is to have a basic shelter. To embrace the formal city, the government actions either adapt or destroy the informal grid, move the population to other areas and define public spaces alongside the river, aiming to control the land use at its margins. In this region of the city, coexist three situations: the formal areas with planned grid and settlements; the informal adapted areas, that were absorbed by the formal city through government actions; and the informal areas, marked by the discontinuity of the grid and the concentration of the precarious settlements.

Over the years, the population occupied free spaces in the city, which include the areas alongside the River Maranguapinho's margins, where they live apart from the "official city". As previously mentioned, the interventions at the urban grid promoted at first the removal of the inhabitants—physically from their houses—and secondly, they are exposed to be gradually expelled from the area by the real estate speculation dynamics that create difficulties to maintain the life in places with increased financial value.

Political and economic interests modify the city's spatial configuration. The implementation of the urban infrastructure, such as sewer system, and the requalification of the river margins are extremely important. However, the expansion of the rectangular grid is a simplistic reproduction of a configurational pattern that does not promote urbanity[1] in global or local scales, once the interventions were not planned to stimulate co-presence in public spaces, land use diversity and pedestrian movement. The urban interventions slowly deliver "organised spaces", with a minimal infrastructure, affecting mostly the inhabitants located in distant areas of the city, that don't have economic access to regular dwellings and live in precarious settlements.

References

1. Hillier, B. (2007) Space is the machine: A configurational theory of architecture. Electronic edition. London: University College of London.
2. Accioly, Vera Mamede. (2008) Planejamento, Planos Diretores e Expansão Urbana: Fortaleza 1960-1992. (Doctoral Thesis). Salvador: Universidade Federal da Bahia
3. Balbo, Marcello. (1993) Urban planning and the fragmented city of developing countries. In: Third World Planning Review, Feb 1993, Vol 15, Issue 1, pp. 23
4. Prefeitura Municipal de Fortaleza (2017). Fortaleza em mapas: informações georreferenciadas de Fortaleza. Available at: <http://mapas.fortaleza.ce.gov.br>
5. Villaça, F. (2001) Espaço intra-urbano no Brasil. São Paulo: Estúdio Nobel: FAPESP: Lincoln Institute.
6. Greene, M. (2003) Housing and community consolidation in informal settlements: a case of movement economy. In: 4th International Space Syntax Symposium Proceedings. London.
7. Hillier, B., Hanson, J. (2005) The social logic of space. Cambridge: Cambridge University Press.
8. Hillier, B. (1999) Centrality as a process: accounting for attraction inequalities in deformed grids. In: Space Syntax Second International Symposium, Brasilia.
9. Hillier, B; Burdett, R.; Peponis, J.; Penn, A. (1987) Creating life: or, does architecture determine anything? In: Architecture and Comportement/Architecture and Behavior. London: UCL Eprints, v. 3, n. 3, p. 233-250. Available at:

<http://discovery.ucl.ac.uk/101/1/hillier-etal-1987-creating-life.pdf>

10. Hillier, B.; Greene, M.; Desyllas, (2000) J. Self-generated Neighbourhoods: the role of urban form in the consolidation of informal settlements. In: Urban Design International 5, pp 61. London: Stockton Press.
11. Holanda, F. de. (2013) 10 mandamendos da arquitetura. Brasília: FRBH, 2013.
12. IBGE (2010) Instituto Brasileiro de Geografia e Estatítica—Censo 2010. Available at: <http://censo2010.ibge.gov.br>
13. IBGE (2016) Instituto Brasileiro de Geografia e Estatítica—Estimativa populacional para os municípios. Available at: <http://www.ibge.gov.br/home/estatistica/populacao/estimativa2016/estimativa_dou.shtm>
14. Karimi, K.; Amir, A.; Shafiedi, K.; Raford, N.; Abdul, E.; Zhang, J.; Mavridou, M. (2007) Evidence-based spatial intervention for regeneration of informal settlements: the case of Jeddah central unplanned areas. In: 6th International Space Syntax Symposium Proceedings. Istanbul.

CHAPTER SEVEN

DEVELOPMENT OF A PERMEABILITY MEASURE BETWEEN PRIVATE AND PUBLIC SPACE[(1)]

PATRICIA ALONSO,
META BERGHAUSER PONT,
LUIZ AMORIM

Introduction

The Natural Movement theory[1] states that street configuration is the primary generator of pedestrian movement and activities, which influence each other. Further, it is often pointed out that high density also generates a higher intensity of activities and movement in cities.[2, 3, 4, 5]

However, in certain urban contexts, such as Latin American cities and, more specifically in this study case, Brazilian cities, this may not be the case. In these cities, urban developments with high street centrality and density can present the low presence of people in public spaces.

The hypothesis is that this is caused by the specific way densification takes place. Present-day Brazilian cities have a typical verticalization process, which is primarily aimed at housing. High-rise residential buildings reach more than twenty or even forty storeys, with a semi-underground floor and often a ground floor for car parking, due to an urban planning and mobility policy that prioritises motorised private transport.

We focus on the analysis of two characteristics related to this densification type, which seem to contribute to less inviting and less safe streets. First, the larger size of plots. Due to urban legislation requirements for a more

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balanced relationship between the total built area and plot area, higher buildings demand larger plots. These are achieved by joining several plots and reducing the number of plots per block. Second, the consequent lower frontage permeability. Because of fewer entrances and the presence of blind walls due to semi-underground floors for car parking there is less interaction between private buildings and public streets.

Some authors discuss the plots influence for socioeconomic processes in cities. The spatial capacity concept[6] states that plot systems can potentially contribute to urban diversity from a socioeconomic perspective. Marcus[7] affirms that the plot indicates an actor presence with particular action strategies in the city. Thus, an area with many plots would tend to present a higher amount of such actors and strategies. These diverse strategies would lead to greater potential for diversity of land uses. Bobkova *et al*. states that a greater variety in plot sizes may also have an impact on diversity, due to consequent differences in functions.

Renowned authors, such as Jacobs,[2] Gehl,[9, 10] and Panerai *et al*.[11] refer to the importance of the interaction between public and private spaces with the quality of public spaces and active street life. Jacobs' "eyes on the street" concept[2] very clearly shows how visual permeability between plots and streets can contribute to a street's vitality and safety.

The Space Syntax's "constitution"[12 (2)] is a method to map the interface between the streets and the buildings: links between buildings or plot boundaries and convex spaces[2] are drawn when there is a relation of direct adjacency and permeability between them, thus representing entrances. The map shows how constituted (directly adjacent and permeable) the convex space is in relation to buildings. Hanson[13] developed this further and introduced the "constitutedness rate", which quantitatively describes the percentage of convex spaces that are constituted by entrances.

Nevertheless, the frontages' assessment still needs to be addressed in a more comprehensive and thorough way. This paper's contribution is to introduce a measure that captures the frontage permeability, both in qualitative and quantitative terms, by verifying a) the frontage visibility and accessibility separately; b) the presence of setback, its depth and use; and c) the type of space (referring to land use) where there is permeability.

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(2) Convex spaces refer to the urban space representation in its convex fragments, that is spaces in which no straight line drawn between any two points goes outside the space[12] (pp. 97–98).

This paper describes the developed method to measure frontage permeability. It briefly describes measuring procedures for density and plot sizes based on existing methods, and the measures for network centrality and accessibility. Then, it presents a pilot study of the permeability measure in selected areas of a district in João Pessoa, Brazil, in order to evaluate the relationship between this measure and density, plot size, frontage length, and land use. The final part presents the test results, conclusions, and the next research steps: expanding the test area and correlating the results to socioeconomic data (people's co-presence in the streets and land uses).

The content of this paper is part of a doctoral research project on the relations between density and urban form and its influence on urban social performativity.

Methodological Procedures

Development of a Permeability Measure

For the purpose of this research, frontage permeability is understood as the property of these frontiers to allow interpersonal interactions between the spaces delimited by them: namely, the public space (the street) and the private space (the plot). These interactions may be visual—people on the streets may or may not see what goes on inside the plot, and vice-versa—or also physical—people may or may not cross the border between the public and private spaces defined by the frontage. It needs to be understood that these interactions have a certain inequality.

The public space is, by definition, commonly open and accessible to all people, while the plot, often being privately owned, tends to have controlled visibility and access. The frontage partition, for example, may purposefully conceal the view from the street to the plot, but not the opposite. In the same way, doors and gates aim at controlling the access to the plot, rather than the exit to the public space. The study looks at the interface public-private from the public space perspective, which is the stage for people's co-presence and interaction.

In the proposed method, the Permeability measure was divided into two variables: Visibility (the property of the frontage to allow people to see through it) and Accessibility (the property of allowing people to pass through it). These variables are measured separately, as they are not necessarily correlated. For instance, due to the use of transparent material, a frontage with high visibility may not be accessible, and a high and opaque gate can completely block eye contact.

The Visibility and Accessibility measures were defined by combining the degree, which is a quantitative measure of how visually or physically permeable the frontage is, to a qualitative evaluation about the type of space in terms of its visibility or access. This type refers to a socio-spatial qualification according to the land use—if is it a public or private space, occupied, underutilised, or empty. This differentiation is important as the contribution of street-plot constitution to urban vitality is beyond the physical possibility of seeing or passing through the frontier between them. Having visibility in a vacant plot, for example, presumably does not contribute to the quality, safety, or vitality of the streets.

To measure the Visibility variable, we defined four categories: no visibility (v1); visibility to empty space (v2); visibility to private space (v3); and visibility to (semi-)public space (v4). The "empty space" class includes vacant plots, and residual and underutilized spaces, which were defined as follows: vacant plots are private plots without occupation and use; residual spaces are small areas between buildings within plots, without a defined function and which are idle; and underutilized spaces are those whose uses are not useful for social interactions, such as closed or abandoned buildings, parking lots and garages. The "private space" class was comprised of single-family and multifamily residential uses, while "(semi-)public space" encompasses all other public, semi-public, or collective uses: retail and services, etc. This scale is based on the principle that visibility to a (semi-) public space has more potential to promote an interaction between the street and the plot than that to a private space, which is usually more controlled and isolated. Likewise, cisibility with regard to a private space generates more potential interaction than the vision of an empty space, which only surpasses the no visibility condition.

The definition of land-use, and the concepts and degrees of public-private are much more diffused and complex than this categorization. However, we tried to avoid a model with too detailed (and thereby non-generic) or too abstract (and thereby too broad) categories. The developed method seems to be effective enough to differentiate the basic types of land use, and economic enough not to be too complicated.

The Accessibility variable measure is also based on a four-category scale: no access (a1); controlled access to private space (a2); controlled access to (semi-)public space (a3); and open access (a4). It was necessary to differentiate the controlled access from open access. It is not necessary to qualify the plot use when an open access is found. Given its quality of being devoid of barriers, it does not matter if the open access is to a public or private space, or even to an empty one. An open access to a private or semi-public space sets up an urban kindness that promotes the convergence between street and plot spaces. When it is directed to an empty space, it can promote space occupation, as commonly seen in Brazilian cities (often lacking in squares and public equipment for leisure and sports) where the open (with no walls) vacant plots are spontaneously converted by the population into football fields.

A “controlled access to empty space” category was not necessary. The entrances of closed buildings and that for the exclusive use by cars were registered in the “no access” category. In the first case (closed buildings), there is no access. In the second case (parking lots and garages), there is a controlled access, which is only used by vehicles, so it does not generate social interaction between street and plot. The mixed-use gates, which are for both pedestrians and vehicles, were considered as accesses.

Another variable recorded and analysed for each plot was the Set Back. When there is a barrier between street and plot, which is set back from the street, a private plot space is “given” to the public street. It was verified that, if a set-back space is found, its dimension and its eventual occupation were analysed. When a set back is present, depending on its use, it can have a positive (generating gradations between public and private spaces, with semi-public uses) or negative effect (creating distances, residual spaces) in the interactions between these spaces. Once the variables and their categories of analysis were defined, frontage mapping was conducted in the chosen areas, using Google Street (with updated data from July 2017) and Google Earth tools for data gathering. Visibility values were registered based on the average height of the eyes of a pedestrian (about 1.60m). Based on the possibility of visual interaction with the ground level of the plot, an opaque barrier of 1.70m or higher was classified in the “no visibility” category. In situations of discontinuous vision, due to, for instance, the presence of fences, interspersed posts or hollow bricks, visibility was considered to exist.

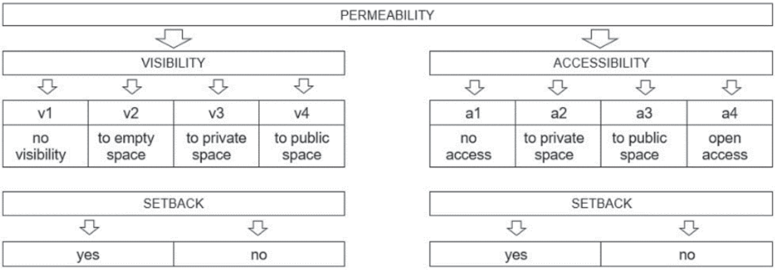

Table 07.1

Permeability measure scheme.

In Accessibility, the "open access" category was set for situations with no barriers higher than 40cm from the sidewalk level. Obviously, a 50cm high wall can also be crossed. But the height limit to open access was defined considering the intention of territory demarcation. Space accessibility is not only about being able to transpose, but also about permission to transpose.[14]

The lengths were measured in meters (recesses were considered irrelevant and thus not measured). The distinct frontage conditions for Visibility and Accessibility of each plot were verified and recorded in order to describe plot's frontage as the sum of several entities, according to the variables' values. This level of detail is relevant, since the boundary of a plot can be very heterogeneous along its length. In that case, assigning only one Accessibility or Visibility value to it will not express its actual condition.

For the geometric representation, lines were used with attributes according to Table 07.1. Further, the line length was added as an attribute and, in case of a setback, its depth and use. The length of each permeability category was measured to then develop various indexes to describe the frontage permeability of each plot. The indexes were calculated as shown in Figure 07.1.

$$VI = 1-(v1/(v1+v2+v3+v4)) \quad (1)$$
$$AI = 1-(a1/(a1+a2+a3+a4)) \quad (2)$$

where

VI = Visibility Index
v1 = frontage length with no visibility
v2 = frontage length with visibility to empty space
v3 = frontage length with visibility to private space
v4 = frontage length with visibility to (semi-)public space
AI = Accessibility Index
a1 = frontage length with no access
a2 = frontage length with controlled access to private space
a3 = frontage length with controlled access to (semi-)public space
a4 = frontage length with open access

Figure 07.1

Main indexes of frontage permeability: Visibility Index and Accessibility Index.

Some sub-indexes were developed to test the effect of the permeability categories, describing what is visible or accessible. To test the impact of permeability to public spaces, the formulas shown in Figure 07.2 below were used:

$$VI_{pu} = v4/(v1+v2+v3+v4) \quad (3)$$
$$AI_{pu} = Na3/(a1+a2+a3+a4) \quad (4)$$

where

VI_{pu} = Visibility Index to public space
AI_{pu} = Accessibility Index to public space
Na3 = number of controlled accesses to (semi-)public space.

Figure 07.2

Sub-indexes of frontage permeability: Visibility Index to public space and Accessibility Index to public space.

Further, we added measures for permeability to both public and private space, and to open access using the formulas shown in Figure 07.3:

$VI_{pri\ pu} = (v3+v4)/(v1+v2+v3+v4)$ (5)
$AI_{pri\ pu} = (Na2+Na3)/(a1+a2+a3+a4)$ (6)
$AI_{op} = a4/(a1+a2+a3+a4)$ (7) where

$VI_{pri\ pu}$ = Visibility Index to public and private space
$AI_{pri\ pu}$ = Accessibility Index to public and private space
Na2 = number of controlled accesses to private space.
AI_{op} = Accessibility Index for open access

Figure 07.3

Sub-indexes of frontage permeability to both public and private space, and to open access.

In formulas 4 and 6, the numerator indicates the number of accesses, rather than the length (the number seems to be more effective for the assessment in these cases than the amount in meters).

Formula 3 can demonstrate the potential urban diversity since it registers the visibility index for all non-private uses. Formula 5 can express Jacob's "eyes on the street",[2] as it registers the visibility index for all public and private uses.

Measures of Density and Plot Sizes

In order to test the hypothesis, the permeability indexes were related to the local density, plot size, frontage length, and land use.

The Spacematrix method was used for density measures.[15] It calculates the built density using multiple density indexes including the Floor Space Index (FSI)[(3)] and the Ground Space Index (GSI), which together have shown to effectively describe building types. The results are represented in diagrams that synthesise various density characteristics of the analysed areas and classify the types found.

The measures related to the plot size were based on Bobkova et al.,[8] who developed morphological measures of plot systems, capturing size, openness, and compactness, and configurational measures for the accessible

[(3)] Also referred to as the Floor Area Ratio (FAR).

number and diversity of plots using the Place Syntax Tool (PST).(4)

The local measurements in the test areas were combined with configurational measures at the district level, using Space Syntax[16] network centrality measures: integration and choice(5) at a range of scales (radii 500m, 1km, up to 5km, and in the topologic radii r3, r7 and r12). Furthermore, accessible density and accessible number of plots were measured for various scales (500m, 800m, 1km, up to 5km walking distance) using PST.[17, 18]

Pilot Study

The initial tests were performed in selected areas of Manaíra district, in João Pessoa, Brazil. (6) Manaíra integrates the high-income coastal subcentre(7) of João Pessoa, which is one of the new centralities of the city in a process started in the 1970s.[19]

Manaíra has 26.369 inhabitants in 2,42km^2, with a high population density of 10.896 inhab/km^2. It is the city's fourth most populated district (in absolute numbers) and the seventh most densely populated. It is also among the districts that present the highest built densities in the city. Integration and choice values indicate that Manaíra presents high centrality and accessibility in all radii. Accessible density measure also shows high values in all radii. Therefore, Manaíra district presents economic-functional centrality (it is a subcentre with housing, retail, and services), demographic centrality (high population density), and morphological centrality (high FSIs, and, in configurational terms, high centrality, accessibility, and accessible density). Based on the Natural Movement theory,[1] we would expect high levels of pedestrian movement and activities which, however,

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(4) PST is a plug-in tool for QGIS that uses Space Syntax analysis for measuring the accessibility through the street to different contents of urban space (e.g., density or plot area), rather than the accessibility of the streets themselves. The PST measures can be said to be closer to the cognitive experience of a person walking through urban space, and his or her perception of variations in densities, plot sizes, and types of buildings, etc.

(5) Also referred to as closeness centrality and betweenness centrality, respectively.

(6) João Pessoa, capital of Paraíba province in Brazil, has a population of 811.598inhabitants in 211,5 Km^2, and a population density of 3.837 inhab/km^2. It is part of a 1,26 million inhabitant metropolitan area (data from 2016–2017).

(7) Subcentres result from urban expansion, concentrating retails and services in housing areas, in order to reduce user displacements in search of urban facilities. Unlike traditional centres, subcentres usually serve only parts of the city (Villaça, 2001).

does not seem to be the case.

Four areas were selected for initial testing in Manaíra (see Figure 07.5). Areas 1 and 2 present the highest values of accessible density in local radii (500m and 800m) within the district range. Areas 3 and 4 presents medium to high accessible density values in the same radii within the district range, and they are next to malls that act as attractors.

As the testing areas have high centrality and accessible density, they would be expected to present urban vitality. The other variables (plot size and frontage permeability) that were measured may, according to our hypothesis, affect this relation between density, centrality, and urban life.

The permeability measures are related to local density, plot size, frontage length, and land use. This paper does not relate the morphological data to people's co-presence in the streets. This is the next step in the research.

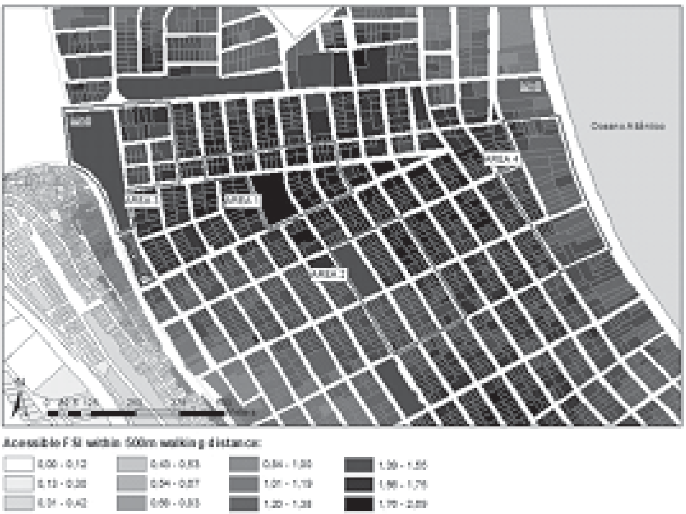

Figure 07.4

Map of a section of Manaira district (João Pessoa, Brazil), with testing areas marked, showing accessible FSI within 500m walking distance.

Findings

The visibility and accessibility maps (see Figure 07.6) show an overview of the frontage permeability in the testing areas, demonstrating that in all areas there are many frontages with low visibility. There are also particularities: area 1 presents more frontage permeability to private spaces, indicating to be a more residential stretch. Area 2 is more commercial, since it presents more frontage permeability to public spaces (retail and services). Areas 5 and 6 are mixed: they present stretches with permeability to residential areas close to stretches with permeability to public spaces. The graphs that relate the Visibility and Accessibility Indexes (VI and AI) to the FSI values of each plot do not demonstrate a statistical correlation between these variables. However, they record a pattern: in the low and medium densities (up to approximately FSI=3), the entire range of VI and AI is present. But at high densities (FSI above 3 to 8), both indexes remain low (see Figure 07.7). This pattern is repeated in the indexes' comparisons with plot area and frontage length. It also occurs with the Visibility and Accessibility sub-indexes for public spaces (VI_{pu} and AI_{pu}) and for private and public spaces (VI_{pripu} and AI_{pripu}). Therefore, the repeated pattern confirms the hypothesis that the high-rise residential buildings type, which is being implemented in the city, causes not only urban densification but also a decrease in frontage permeability.

Further, there is no statistical correlation between AI and VI, that is, accessibility and visibility do not necessarily occur together, which confirms the pertinence of the proposed method in measuring these two variables separately (see Figure 07.8).

Figure 07.8 also shows that both public-use plots (retail and services) and those with other uses (housing, underutilization, and no use) present high and low frontage permeabilities, although in plots with other uses, the low values predominate. This indicates that the frontages of public-use plots are not necessarily more permeable; this is confirmed in the two charts in Figure 07.9, which relate number of plots with public uses and other uses to VI and to AI, respectively.

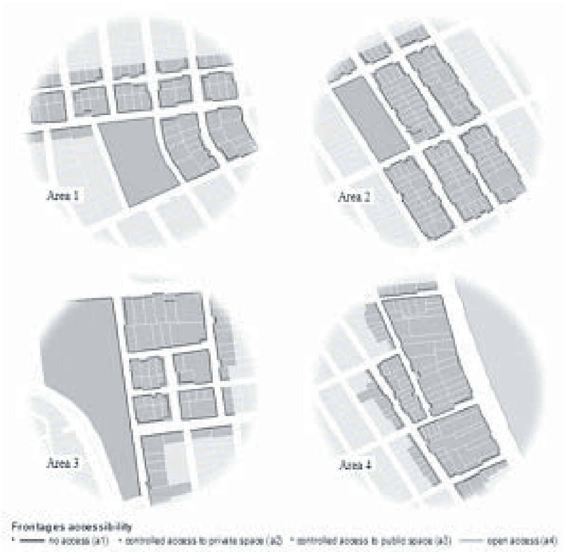

Figure 07.5

Maps of the four testing areas, showing the frontages' visibility and accessibility.

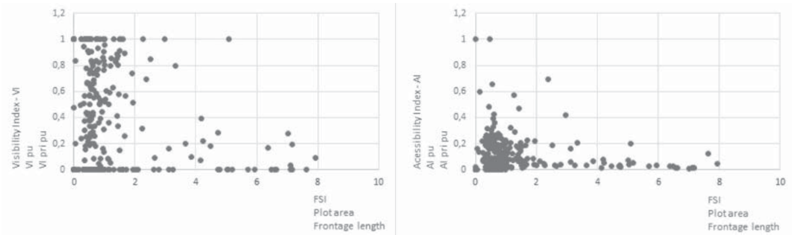

Figure 07.6

The chart on the left summarises the relation between the Visibility Indexes and FSI, plot area, and frontage length values. The chart on the right summarises relation between the Accessibility Indexes and FSI, plot area, and frontage length values.

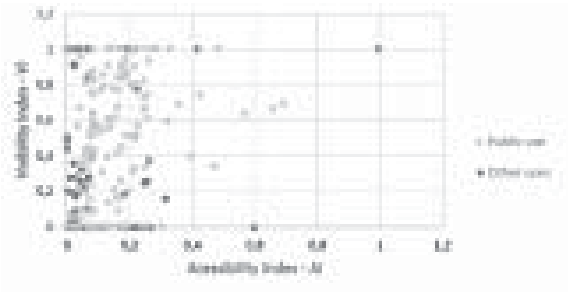

Figure 07.7

Chart with the relation between the Accessibility Index (AI) and the Visibility Index (VI).

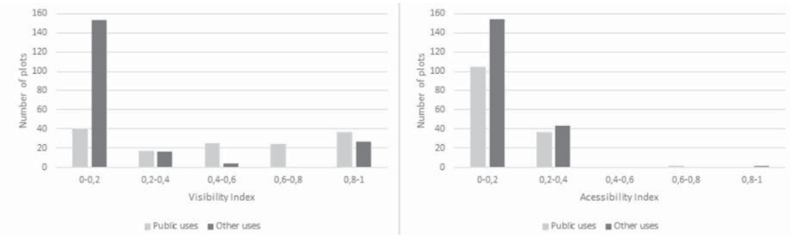

Figure 07.8

On the left, chart with the relation between the Visibility Index and land uses (public or non-public). On the right, chart with the relation between the Accessibility Index and land uses (public or non-public).

We found a strong correlation (R^2=0.48) between the AI_{pu} and VI_{pu} indexes (see Figure 07.10), which indicates that, when there is higher visibility for public spaces, there is also higher accessibility. This data demonstrates how permeability to public spaces—which tends to simultaneously include access and visibility—can play an important role in creating conditions for urban diversity. But the indexes of $AI_{pri.pu}$ and $VI_{pri.pu}$ have no strong correlation (R^2=0,16). These relations (between AI_{pu} and VI_{pu} and between $A_{pri.pu}$ and $VI_{pri.pu}$), when analysed together, indicate that there is a mismatch between accessibility and visibility in the frontages of residential spaces.

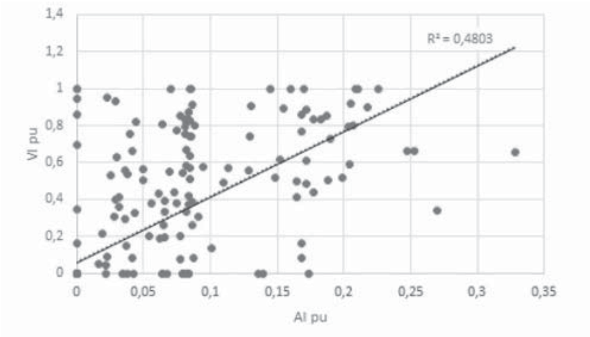

Figure 07.9

Chart with correlation (R2=0.48) between Accessibility Index to public spaces and Visibility Index to public spaces.

The sub-index AI_{op} (for open access) is always very low in any graph, demonstrating that open access is rare. In terms of setbacks, they are mostly used for parking and do not contribute to social interactions.

The moderate correlations between density and plot area (R^2=0.22) and between density and frontage length (R^2=0.25) show that there are still many buildings with high FSI in relatively small or medium plots, and with low or medium frontage length. Therefore, the hypothesis that the verticalization type in focus brings about bigger size plots is not confirmed.

Conclusions

The proposed method of measuring the frontage visibility and accessibility separately proved to be pertinent, since the results confirm that these variables do not necessarily go together. The results also indicate that verifying the land use where there is permeability is relevant: the frontages of public spaces (retail and services) are not always more permeable, but, when they present higher visibility, there is also higher accessibility, which does not necessarily happen in private spaces frontages.

The initial results confirm the hypothesis that the increasing densification model in Brazilian cities with high-rise residential buildings generates a decrease in the frontages' permeability, although this model does not appear to significantly change the plot sizes and the frontages lengths. Therefore, the dissemination of this building type generates a low interaction between streets and plots, since it is often surrounded by blind walls with no visibility and few access points. Especially when this model is repeated in adjacent plots and creating a continuity of impermeability. (when these buildings are built side by side), it generates a poor, desolate, and unsafe urban environment, without quality, diversity, or the beneficial "eyes on the street" mentioned by Jacobs.[2] These for passers-by unattractive urban areas tend to be empty, lacking urban life.

According to the results, there are also less dense types that have low frontage permeability. However, these cases commonly have isolated walls, which can be easily modified or demolished to generate higher permeability. In high-rise residential buildings, most of the frontages are semi-underground garages walls that are more permanent structures and more difficult to modify (see Figure 07.11).

Figure 07.10

Frontages of high-rise residential buildings in Manaira: walls of semi-underground and ground floor garages.

Furthermore, the pattern of low permeability indexes in plots with longer frontages indicates a contradiction and a waste of space. Though more linear meters could be used for higher diversity and more "eyes on the street", the opposite occurs.

It is worth stressing the role of urban planning and management in controlling this lack of frontage permeability. It would be advisable for urban legislation to establish minimum percentages of frontage permeability. It would also be pertinent to stimulate the mix and multiplicity of uses, thereby guaranteeing the presence of public uses, but it should be stressed that the use is easier to change than the built structure, making formal permeability an important factor.

The results presented here are preliminary. Other empirical studies need to be carried out in other districts and in other cities in order to obtain more complete and representative data, which may lead to more assertive conclusions. In the next stages of the research, the testing areas will be expanded (including another district), and the morphological data will be related to people co-present in the streets to try to verify the role of each variable on co-presence and related social processes related.

References

1. Bill Hillier, Alan Penn, Julienne Hanson, T. Grajewski, J. Xu, Natural movement: or, configuration and attraction in urban pedestrian movement. Environment and Planning B: Planning and Design, v. 20, n. 1, p. 29–66, 1993.
2. Jane Jacobs (1961). Morte e vida nas grandes cidades. Trad. C.S.M. Rosa. São Paulo: Martins Fontes, 2000.
3. Richard Rogers (1997). Cidades para um pequeno planeta. Trad. de Anita Regina Di Marco. Barcelona: Gustavo Gili, 2014. ISBN: 978-84-252-1889-7.
4. Mike Jenks; Rod Burgess (org.) (2000). Compact Cities: Sustainable Urban Forms for Developing Countries. London: Taylor & Francis e-Library, 2004. ISBN 0-203-78686-6.
5. M. Richard, Higher development density: myth and fact. Washington, DC: ULI, Urban Land Institute, 2005.
6. F. Villaça, Espaço intra-urbano no Brasil. São Paulo: Studio Nobel, 2001.
7. Lars Marcus, Spatial Capital: A Proposal for an Extension of Space Syntax into a More General Urban Morphology. The Journal of Space Syntax, London, 1, p. 30–40, 2010.
8. Evgenyia Bobkova; Lars Marcus; Meta Berghauser Pont. Multivariable Measures of Plot Systems: Describing the potential link between urban diversity and spatial form based on the spatial capacity concept. In: 11th International Space Syntax Symposium, 2017, Lisboa. Proceedings of the 11th International Space Syntax Symposium. Lisboa: Instituto Superior Técnico, Departamento de Engenharia Civil, Arquitetura e Georrecursos, 2017.
9. Jan Gehl (1971). La Humanización del Espacio Urbano: La vida social entre los edificios. Trad. de María Teresa Valcarce. Barcelona: Reverté, 2006.
10. Jan Gehl (2010). Cidades para Pessoas. Trad. de Anita di Marco. 2ª ed. São Paulo: Perspectiva, 2013.
11. Philippe Panerai, Jean Casttex; Jean-Charles Depaule (1977). Urban Form: The death and life of the urban block. Translated by Olga Vitale Samuels. Oxford: Architectural Press, 2004. ISBN 0-7506 5607-7.

12. Bill Hillier; Julianne Hanson. The social logic of space. London: Cambridge University Press, 1984.
13. Julienne Hanson, “Urban transformations: a history of design ideas”. Urban Design International, London, 5, p. 97–122, 2000.
14. Eva Minour. Uncommon Ground:Urban Form and Social Territory. Stockholm: KTH Royal Institute of Technology, School of Architecture and the Built Environment, 2016. Doctoral thesis in Architecture.
15. Meta Berghauser Pont; Per Haupt. Space, Density and Urban Form. Delft: Technische Universiteit Delft, 2009. ISBN: 978-90-5269-375-0.
16. Bill Hillier, Space is the machine. A configurational theory of architecture. London: Cambridge University Press, 1996.
17. Lars Marcus, Meta Berghauser Pont; Evgenyia Bobkova. Cities as Accessible Densities and Diversities: Adding attraction variables to configurational analysis. In: 11th International Space Syntax Symposium, 2017, Lisboa. Proceedings of the 11th International Space Syntax Symposium. Lisboa: Instituto Superior Técnico, Departamento de Engenharia Civil, Arquitetura e Georrecursos, 2017.
18. Meta Berghauser Pont; Lars Marcus. Innovations in Measuring Density: From Area and Location Density to Accessible and Perceived Density. Nordic Journal of Architectural Research, Oslo, 2, p. 11–30, 2014.
19. P.A.F. Andrade, E. Leite Ribeiro; J.A.R Silveira. Centralidade urbana na cidade de João Pessoa – PB. Uma análise dos usos comerciais e de serviços entre o centro tradicional e o centro seletivo – 1970/ 2006. Arquitextos Vitruvius, São Paulo, 106.06 ano 09, mar. 2009. Disponível em: <http://www.vitruvius.com.br/revistas/read/arquitextos/09.106/69>. Access in 1 out. 2016.

CHAPTER EIGHT

THE CENTRALITY OF (VOCATIONAL-ORIENTED) KNOWLEDGE: AN ASSESSMENT OF THE LOCATION OF POLYTECHNIC INSTITUTES IN PORTUGAL[(1)]

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LUÍSA CANNAS DA SILVA,
TERESA VALSASSINA HEITOR,
REEM SHURUSH

Introduction

The current global context, in which knowledge has assumed a preponderant development role at multiple levels, has changed the perceived impact of higher education institutions (HEi). Their social responsibility and impact on society at large has increased, since access to higher education has been democratised and the student population has simultaneously increased and become more diversified worldwide.

Globally, initiatives, such as the Bologna Process and comparable processes, implied a global simultaneous uniformization, which affected higher education and impacted not only on student enrolment and the mobility of students, academics, and staff, but also on educational policies, and pedagogic methods and strategies. Beside the fact that HEi have been in the core of change and development—economic, social, and inter-alia—their role within urban context has changed in order to respond to the third strand of the university mission—that of civic engagement. Higher education

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[(1)] This chapter was previously published in the Special Issue "Formalizing Urban Methodologies". *Urban Sci.* 2018, *2*(3), 75; https://doi.org/10.3390/urbansci2030075.

institutions are a key element in urban dynamics and policies, and they are progressively more included in strategic plans and development actions worldwide. Therefore, it has become significant to understand the extent of the institutions' integration within urban territories, for this integration enhances the institutions' capacity of fostering connections with its adjacent territories.

In Portugal, particularly, higher education has strongly changed since the 1970s, and it is expected that it will continue to transform and evolve. It presents a fairly diverse offer in terms of types of higher education institutions. This diversity is perceived by policymakers as a strong asset, since it allows for a comprehensive response when it comes to meet the needs of a diverse range of learners, and of complex knowledge societies[1] (p. 34). This diversity is greatly heightened by its organisational system, which is grounded on a binary structure and which makes universities differ from polytechnic institutions. Polytechnic institutions differ from universities in terms of mission, focus, and formative offer. Their focus is mostly regional, and often their offer in terms of courses and study fields is directly related to the regional economies in their areas. According to Portuguese legislation, "polytechnic institutions are high level institutions oriented towards the creation, transmission, and diffusion of professional type culture and knowledge, through the articulation of teaching, learning and oriented research and experimental development"[2] (Art. 7), and "should focus on vocational training and advanced technical development, professionally oriented"[3] (Art. 3). This binary structure greatly contributes to the diversification that exists in Portuguese higher education, which is visible in terms of the student body, the formative offer, and the institutional profiles, particularly as polytechnic institutions have a very large representation in terms of enrolment, as they host about 34%[(2)] of the total amount of students.[3] Besides, polytechnic institutions present a very large potential to fulfil the third strand mission of higher education for their proximity to regional contexts and professional-oriented vocation. For these reasons, it is necessary to understand how these institutions relate with their urban territories, particularly considering their proximity relations. This paper focuses on the impact of these relations, as it attempts to understand the ways higher education institutions can relate to their hosting cities from a morphological point of view. It aims at exploring the location of polytechnic institutes within their hosting cities, identifying correspondences and patterns in different institutions, and considering the potential impact of these locations in the engagement with the hosting city. Its main goal is to provide an analysis framework for higher education infrastructures within

[(2)] This number refers to the academic year of 2015/2016.

urban fabrics, as well as understanding the different types of urban insertion and connections established with local and regional players.

Figure 08.1

Polytechnic institutions geographic dispersion in mainland Portugal.

Methodology

This paper is grounded on an exploratory methodology to access the centrality features of higher education institutions. It is tested through its application to the analysis of two case studies: the Polytechnic Institute of Beja and the Polytechnic Institute of Bragança. It presents a direct comparison of schools that cover the same field, namely the Agrarian Schools and Health Schools in both institutions. However, it is intended for a broad application.

The research is developed at two scales: the first (a) focuses on the location of the institution in its hosting city, while the second (b) focuses on the depth of the spaces within the premises of the institution.

For the first stage, Space Syntax techniques[4, 5, 6, 7, 8] are used. The cities are represented through a segment map,[9] that operates as a base map for the analysis. The segment map is a development of the fewest line map (axial map) defined by Space Syntax theory that considers that the segments between intersections as elements in themselves, in opposition to axial lines, which are continuity lines. This map, while providing sufficient geographic information to allow for a clear identification of the precincts' location, performs as base map for angular analysis.[10, 11] In this analysis, two main variables are chosen in order to better understand the institutions' location within the urban territory—closeness centrality, accessed through normalised angular integration, and betweenness centrality, accessed through normalised angular choice[12]—in order to better understand the potentials of both to-movement and through-movement of the higher education institutions. This analysis is performed at global (Rn) scale, considering the full extension of the cities scoped.

The second scale of analysis—the micro scale—focuses on the services the institution has the potential to offer to its hosting community, through the spaces that can be used by the non-academic community, in order to access the institution's third mission potential. These spaces are evaluated according to their deepness within the institution's buildings, through justified graphs. This methodology allows us to infer the ease of access to each space of the institutions, and to extrapolate on their perceived importance through the configuration of the physical spaces. Spaces are assessed in terms of their relationship to all other spaces, more than in terms of their physical characteristics.

Case Studies

Beja and Bragança were chosen as case studies for their local and regional importance, being the cities hosting polytechnic institutions at the most southern and northern locations, respectively, within the mainland territory of Portugal and for the similarities in terms of formative offer. In the context of these cities, polytechnic institutions have highly contributed for local and regional development, as they are very important employers in their respective cities and strong development promoters.

Beja currently hosts about 23.500 inhabitants, spread in approximately 7sq. km. It is the siege of the Polytechnic Institute since 1979, when the Agrarian and Education Schools were created. In 1991, the institution's formative offer was complemented with the creation of the Technology and Management School and, finally, the Health School was created in 2002.

Bragança hosts around 24000 inhabitants, spread within the approximately 10sq. km that compose the area of the city. The Polytechnic Institute was created in 1983 and is nowadays composed of four schools located in Bragança—Agrarian, Technology and Management, Education, and Health—and one school located in Mirandela, about 60km from Bragança, the School of Communication, Administration, and Tourism.

Macro Scale

Segment Analysis

The two cities present very different urban fabric structures, which is highlighted by their segment map configurations. Beja's urban fabric shows a grid overlaying a radial structure (Figure 08.2). Bragança, on the other hand, presents an organic layout (Figure 08.3). Bragança shows more than twice the number of axial lines than Beja, and about 1,7 times the number of segment lines. This demonstrates that, besides its larger size, its structure is also more fragmented than Beja—a fact that is underlined by a lower ratio between axial and segment lines. This fact is also verified by comparing the average line length, of 143m in Bragança (where the maximum line length is roughly 1.400m), and of 160m in Beja (where the maximum line length is about 2000m).

Figure 08.2

Beja axial map.

Figure 08.3

Bragança axial map.

These structural features of the cities justify the fact that Bragança presents lower values for normalised angular integration (NAIN) than those observed in Beja, despite its larger size and higher number of both axial and segment lines. In terms of normalised angular choice (NACH), both cities present similar behaviour. The location of the Polytechnic Institutes differs in both cities. Despite the fact that both precincts are considered inner precincts,[13] there are some differences between them. In Beja, the precinct is located at the edge of the urban fabric, but still included within the city's external ring. In Bragança, the precinct is located within the fabric in a relatively central position in geographical terms. However, despite the geographic location within the cities' respective boundaries, in terms of topological centrality, the results are very different.

Figure 08.4

Beja segment map: NAIN Rn.

Figure 08.5

Bragança segment map: NAIN Rn.

In Beja, the integration core overlaps with the central ring (Figure 08.4), which demonstrates the importance of the radial structure of the city. The Polytechnic schools are grounded on the exterior ring, but are still connected to the integration core, due to the small dimension of the city.

In Bragança, the integration core presents a more fragmented structure, which is grounded on the topography of the city. The polytechnic is located in close proximity, south from the city. As such, in both cases, the polytechnic institution does not have the potential to constitute a destination in terms of to-movement in random travels, as far as the system configuration is concerned.

When comparing the urban fabric within the precinct's boundaries, analysed through the values presented by the segment lines that are inscribed within the precinct, we observe slightly higher values of average NAIN in both cases when referenced to the same variable at the city scale. Similarly, in both precincts the main access to the precinct—considering the street in which the main entrance is located—shows a NAIN value above the average of the city, and also slightly above the average of the precinct.

Figure 08.6

Beja segment map: NACH analysis.

The analysis of NACH highlights that the foreground network[14] of Beja is the radial structure that defines the city. The precinct is located in close proximity with this structure; however, it is composed of and part of the background network of the city. A similar situation occurs in Bragança, where the foreground network is more fragmented and organic, but still roots the polytechnic schools, whose fabric is also part of the background network.

Considering through-movement potential, the Polytechnic Institute of Beja presents a better behaviour than its homonym in Bragança, due to the higher value of NACH of its main access, which is located in a street segment that has the potential to be highly used in random travels through the city.

Figure 08.7

Bragança segment map: NACH analysis.

As we can observe in Chart 08.1, Bragança shows the lower minimum, average and maximum values of NAIN. The assessment of NACH shows the cities present very close maximum values, and also similar average values, that fit into the reference values obtained by Hillier, Yang, and Turner.[12]

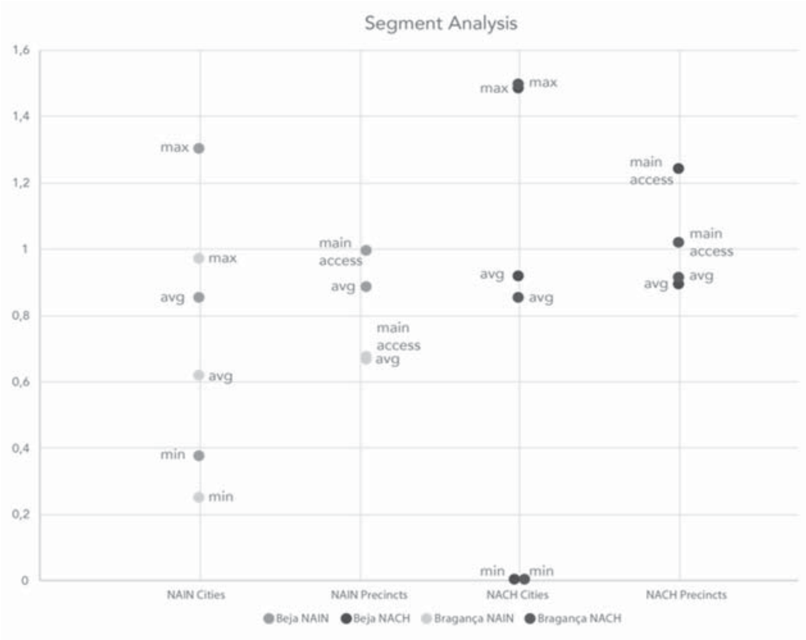

Chart 08.1

Segment analysis summary.

The analysis shows that the polytechnic institutions examined present low values of integration (closeness centrality) which means they have a low potential of becoming to-destinations within their hosting cities. This situation is balanced with the higher values of normalised angular choice (betweenness centrality), especially if considering solely the main entrance of the precinct as a reference, which demonstrate that, in both cases, but more visibly in Beja, the Polytechnic Institutes have the potential to be used in through-movement travels throughout the city. Despite the fact that this feature enhances the precincts visibility, the Polytechnic Institutions examined in this paper are still limited by their spatial configuration in terms of promoting serendipitous encounters when it comes to academic-external community relationships, since spatial configuration plays key role in enabling and promoting encounters and social interaction.[4, 6, 15]

Micro-Scale

Functional Analysis

In order to complement the macro scale analysis, two schools of each institution were assessed in terms of functional and spatial organisation.

Figure 08.8

Precincts of the Polytechnic Institute of Beja and the Polytechnic Institute of Bragança.

Justified graphs (V-E) were made for each school, based on the plans provided by the respective polytechnics, identifying the links between the different spaces. These aim at providing a general characterisation of the organisation layouts of each school, as well as identifying the levels of deepness of different functional spaces. In the scope of this paper and its attempt to investigating the potential level of community engagement in Polytechnic institutions, the focus is placed upon the spaces whose functional offer can be shared with the community, rather than on exclusively academic areas. As such, the following categories were used for the classification of areas: learning spaces, research spaces, administrative spaces, technical areas, circulation areas, accesses, areas with exterior access, auditorium, library, and café. From these, auditoriums, libraries, and cafes were highlighted as the ones that were more prone to promote diversification of users, social interactions, and contribute more towards community engagement.

In each graph, a general exterior point of access was considered, from which all building entrances are connected. This places all entrances at the same accessibility level, assuming each user chooses the entrance nearest to the spaces he wants to reach. Access between floors (vertical circulation) was represented with curved lines, so as to differentiate them from other links. Each accessibility level corresponds to the number of spaces one must go through in order to reach a destination.

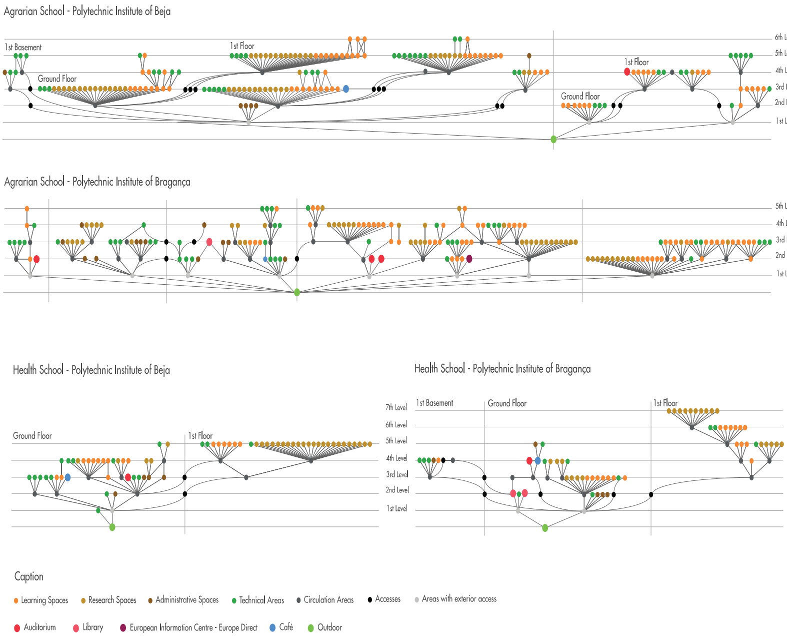

Figure 08.9

Justified graph of the Agrarian and Health Schools, IPBeja and IPBragança.

The Agrarian School of Beja is divided into two independent buildings: one that houses the administrative spaces, research spaces, classrooms, laboratories and café; and another housing the auditorium, classrooms and laboratories.

The first building, that corresponds to the areas identified on the left-hand side of the graph, presents a very clear structure, grounded on the circulation areas, from where it is possible to reach most spaces within the building. It presents a maximum 6 step distance range from the exterior, and areas are distributed similarly among different deepness ranges, apart from the administrative areas, clustered on a highly accessible area. The second building, despite having a different circulation structure, with less clear distribution areas, is one level shallower in terms of global structure than the previous and shows less dispersion of functions. All spaces used by the academic community are located within a 4-step distance reach, and the building presents a maximum 5-step distance range from the exterior, but this maximum distance spaces consist only of technical areas. As a consequence, the perception of the users is of a shallower building.

In terms of functional area prone to be used by the external community, the café is located at the third level of deepness on the ground floor of the first building and the auditorium is at the fourth level of deepness on the first floor of the second building.

The Agrarian School of Bragança stands out for the variation of heights in the terrain and the fact that all floors have outside access. This fact is highly visible in the graph, which presents a structure strongly grounded on the spaces that have access to the exterior, rather than on inner circulation and distribution areas. The graph structure is overall less deep than in the Agrarian School of Beja, although also less clear and seemingly less organised. The functional distribution, however, is similar, with a balanced distribution of spaces among the 5-step distance deepness levels.

There are three auditoriums directly accessible from the entrance, at the second level of accessibility. The café and the library are on the same floor at the second and third accessibility levels respectively. This school houses the European Information Centre of Bragança, Europe Direct, at the second accessibility level.

Comparing both schools, it is perceptible that the Agrarian School of Beja presents a clear and hierarchic structure, that emphasises learning spaces and offices. On the other hand, the Agrarian School of Bragança shows a more organic structure, from which it is not easy to identify a circulation pattern, but enables almost immediate accessibility to most functions, and concentrates all functional area that can have a shared use at a very shallow level from the entrance.

Similarly, to what was verified in the case of the Agrarian School of Beja, the Health School also presents a very hierarchical structure, with a very clear demarcation of functional areas. The school distributes along two wards, and most spaces are grounded on circulation spaces which are parallel to the main façade. The whole building presents a maximum of 5-step distance range, with a shallower structure than the agrarian school. This maximum deepness includes all the research areas and laboratories. The public areas considered, the café and the auditorium, are both located at the entrance floor, within a 4-step distance range from it.

The Health School of Bragança presents a more complex structure, marked by height differences within the same floor, which creates a broader range of deep areas within floors, especially at the ground floor and basement levels. On the upper floor, the distribution of spaces is grounded on circulation spaces as it happens in the Health School of Beja, and similarly, the deepest spaces within the school are research areas and laboratories. Public areas, such as the café and auditorium are located at the main entrance floor, however not occupying the shallower spaces (i.e. the easiest to reach). The library, on the other hand, is highly reachable, being accessed from within the building but also directly from the exterior.

It is noteworthy that the lowest values of centrality showed in Bragança when analysing the precinct at the macro-scale of the city are reversed at the micro-scale. It also becomes visible that the most public areas, and the ones with more potential to be used by exterior users are all placed on the ground floor.

Conclusions

This paper highlights the pertinence of vocational oriented knowledge infrastructure in the context of the binary higher education system currently present in Portugal. It argues that the physical location of polytechnic institutes is a key factor in promoting their integration, which is a vital aspect due to their local and regional impact. Since "the learning campus is one that maximises the probability of chance encounters, and encourages lingering once an encounter—whether by chance or by plan—takes place"[16] (p. 39) efforts should be put into creating opportunities for serendipitous encounters for the academic and the civic community, on both the city and the precinct scales.

This paper aims at providing a methodology for general characterisation of regionally oriented higher education institutions in terms of their location within urban systems, but also as far as the spatial organisation of the institutions is concerned. In this sense, its conclusions rely mostly on the adequacy of the assessment tool rather than on the conclusions of the analysis, which comprehends just two case studies and, for that reason, does not allow for any extrapolation of the results. However, despite its small sample, this analysis raises the question of spatial integration both at the city and the institution scales, and demonstrates that these should be complementary, and jointly thought of during the design process leading to the implementation of a higher education precinct.

The macro-scale analysis creates a framework for analysing both the city's structure and the location of the higher education institutions in this structure by anticipating engagement levels and movement potentials. It allows us to inform the design process at several scales, from the urban planning process of the precincts to each building. It also provides an understanding of what features can be significant in view of the movement potentials achieved in the precinct.

The micro-scale analysis allows us to understand the relative importance given to each space within the precinct. It informs about the general configuration of each building, accessibility levels, easiness in reach each individual space, and circulation systems. It also allows us to infer on the character of each institution, through the closeness or openness of its spaces. This methodology has demonstrated positive results; however, it still needs to be tester on a broader selection of cases. Future developments will include its vaster application in order to obtain clearer results on the integration features of higher education institutions, specifically considering the connections between the two scales of analysis.

References

1. OECD (2007) Reviews of national policies for education: tertiary education in Portugal. Paris: OECD Publishing. doi: http://dx.doi.org/10.1787/9789264009769-en.
2. Assembleia da República (2007) Lei n.o 62/2007 de 10 de setembro, Regime jurídico das instituições de ensino superior, Diário da República - I Série. Portugal.
3. DGEEC (2017) Estatísticas da Educação 2015/16. Lisbon.
4. Hillier, B. and Hanson, J. (1984) The Social Logic of Space. Cambridge: Cambridge University Press. doi: 10.1017/CBO9780511597237.
5. Hillier, B., Hanson, J. and Peponis, J. (1984) 'What do we mean by

building function?', Designing for building utilisation. Edited by J. A. Powell, I. Cooper, and S. Lera. Portshmouth: E & F.N. Spon, 5(3–4), pp. 61–72. doi: 9780419134701.
6. Hillier, B. et al. (1987) 'Creating Life: Or, Does Architecture Determine Anything?', Architecture et Comportement/Architecture and Behaviour, 3, pp. 233–250.
7. Hillier, B. (1996) Space is the Machine. Electronic. Press Syndicate of the University of Cambridge. Available at: http://www.ninsight.at/ak_stdb/SpaceIsTheMachine.pdf (Accessed: 5 November 2012).
8. Al-Sayed, K. et al. (2014) Space Syntax Methodology. 2nd edn. London: Bartlett School of Graduate Studies, UCL.
9. Hillier, B. and Iida, S. (2005) 'Network and Psychological Effects in Urban Movements', in Cohn, A. G. and Mark, D. M. (eds) International Conference on Spatial Information Theory COSIT 2005: Spatial Information Theory. Elliotville, NY, USA: Springer, pp. 475–490.
10. Turner, A. (2000) Angular analysis: a method for the quantification of space, Working Paper Series. 23. London. Available at: http://discovery.ucl.ac.uk/1368/1/paper23.pdf.
11. Turner, A. (2001) 'Angular Analysis', in Proceedings of the Third International Space Syntax Symposium. Atlanta, p. 30.1-30.11. Available at: http://discovery.ucl.ac.uk/35952/.
12. Hillier, B., Yang, T. and Turner, A. (2012) 'Normalising least angle choice in Depthmap and it opens up new perspectives on the global and local analysis of city space', Journal of Space Syntax, 3(2), pp. 155–193.
13. Cannas da Silva, L. (2017) Campus as a City - City as a Campus. A morphological approach to university precincts in urban dynamics. Universidade de Lisboa.
14. Hillier, B. (2014) 'Space syntax as a theory as well as a method', 21st International Seminar on Urban Form. Available at: http://isuf2014.fe.up.pt/.
15. Hillier, B. and Penn, A. (1991) 'Visible Colleges: Structure and Randomness in the Place of Discovery', Science in Context, 4(1), pp. 23–49. Available at: http://discovery.ucl.ac.uk/1007/1/hillier-penn-1991a.pdf.
16. Kenney, D. R., Dummont, R. and Kenney, G. (2005) Mission and place. Strengthening learning and community trough campus design. Westport, CT: Praeger Publishers.

I.2

Other Methodologies in Urban Studies

CHAPTER NINE

POTENTIALITY ANALYSIS FOR URBAN PLANNING

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Introduction

Long-term urban planning is eminently difficult and complex. In Singapore, urban planning is a highly centralised government function, with the Urban Redevelopment Authority (URA) being the designated national land use planning authority[1]. In collaboration with relevant government agencies and public consultation, URA develops a Concept Plan covering strategic land use and transportation and providing broad directions to guide Singapore's physical development over the next 40 to 50 years.[2] This Concept Plan is reviewed every 10 years; the latest review was carried out in 2011-13 and led to the release of the Land Use Plan 2030 by the Ministry of National Development (MND).The latter is a conceptual plan outlining strategies to provide the physical capacity to sustain a high quality living environment for a projected population range of 6.5 to 6.9 million by 2030[3] (which currently stands at 5.61 million as of June 2017[4]).The broad long-term strategies of the Concept Plan are also translated into the Master Plan, a statutory land-use plan that specifies permissible land use and densities, and guides the physical development of Singapore over the next 10 to 15 years.[1] This Master Plan is reviewed about every five years; the latest version dates from 2014 (Figure 09.1).

The Concept Plan ensures that there is sufficient land to support long-term population and economic growth while maintaining a good living environment, balancing housing, industry, commerce, parks, transport, defence and community facilities[1]. Strategies to sustain a high-quality living environment include: providing good affordable homes with a full range of amenities; integrating greenery into the living environment; providing greater mobility with enhanced transport connectivity; sustaining a vibrant economy with good jobs; and ensuring room for growth and a good living environment in future.[2] One possible area for future growth is the Jurong Industrial Estate (JIE), a mono-functional industrial estate incorporating about 4000ha in the west of Singapore. While future developments of public transportation already guarantee improved accessibility to the JIE, the current Master Plan assigns almost exclusively industrial land use (Figure 09.2). JIE is managed by JTC Corporation, Singapore's largest developer of industrial lands. With collaboration from JTC's Urban Planning Department, we adopt JIE as a case study for an urban potentiality analysis with the aim to generate planning scenarios and their argumentation. Our hypothetical assumption for this case study is to convert this almost mono-functional, segregated and fragmented, highly polluted industrial area by 2050 into a major catchment area for future population growth that integrates clean(ed) industrial plants with green lungs, attractive housing and vibrant urbanity for up to one million people to live, work and play.

Figure 09.1

The URA (Urban Redevelopment Authority) Master Plan 2014.

Figure 09.2

The Jurong Industrial Estate in the west of Singapore. Land use categories are taken from the URA Master Plan 2014.

JIE is currently served by one expressway and one Mass Rapid Transit (MRT) line, both running east to west through JIE and linking JIE with Singapore's Central Business District and beyond, as well as one expressway and one MRT line heading north. In addition, two future MRT lines serving JIE are in the planning phase and scheduled to open in 2025[5] and 2030.[6] The entire estate is mainly flat with only one hill of significance, the Jurong Hill, which, next to a recreational park, also sports the Jurong Bird Park, Asia's largest avian wildlife park and the only tourist attraction within JIE. However, the bird park is slated to move to the Mandai Project development elsewhere in Singapore. Obviously, time-dependent issues exacerbate the development of planning scenarios. Land lease ends of current industrial occupants, health and safety buffers relating to existing industrial plants, planned land reclamation and rapid transit developments are still rather straightforward to address as these are well known to the planners. However, other future changes may be largely unknown or at best undecided, including additional land reclamation and further transport network developments, such as the bus network responding to changes in land use, demographics, density, etc. Ideally, scenarios should also take into account issues of liveability and vibrancy, including presence of parks, industry, road traffic exposure, various interdependencies between these and other factors, etc.

The difficulty and complexity of urban planning for the longer-term is not a hindrance to the planning process per se but does affect the efficiency and productivity of the planning process and the ability to conceive and consider sufficient variants in order to gain confidence in the ultimate value of the urban plans and scenarios developed. It is in this context that we are supporting JTC's Urban Planning Department to computationally generate planning scenarios for the conversion of JIE into a mixed-use urban environment. In this paper, we report on the methodology we have developed to identify the potential for urban nodes within JIE as well as related analyses. Urban nodes are here considered as locations for the development of high-density urban neighbourhoods that are attractive for people to live, work, and play.

Methodology

At the large scale, the focus is on identifying the potential for urban nodes within JIE. This potential is influenced by a number of aspects relating to plots and their environment, such as plots' lease ends, health and safety buffers relating to other plots or transport lines that impact the plot in question, accessibility to public transportation, presence of green spaces and waterbodies, exposure to traffic noise, and proximity to industry of various categories. The main approach is a grid-based analysis of the area using GIS data and software (QGIS) over a range of criteria and aggregating these analyses in a hierarchical manner, specifying weights at each level where these weights can be identified as parameters to be adjusted by the planners.

For the urban potentiality analysis, we use an analysis grid rather than plots, as plots may be combined or divided, local (Cat. 5) and primary (Cat. 4) access roads may be added, retraced or even removed, canals may be dug, land set aside for future green or land may be reclaimed from the sea or other waterbodies. We have settled on a 30m x 30m grid, which is small enough for detailed analyses, at the overall scale of JIE or, approximately, even at the level of a single plot or plots, but not too small so as to make the computation process not too heavy. It is also the same resolution as, among others, Landsat 7 satellite images and the United States Geological Survey (USGS) ground cover map. We have adjusted the analysis grid by adding any anticipated reclaimed lands, subtracting expressways (Cat. 1) and major (Cat. 2) and minor (Cat. 3) arterial roads, and subtracting non-industrial land use. At the north-eastern border of JIE are some areas already classified as residential, commercial, or other non-industrial use, and developed as such. As a result of these adjustments, not all grid cells have the same shape or size. However, this does not significantly impact the analysis process.

We are basically adopting a location choice approach,[7] considering 1) land availability, 2) accessibility to transit, 3) presence of parks, 4) presence of industry and 5) traffic noise exposure. Though other relevant factors can be identified or considered, our selection has been mainly driven by data availability. Nevertheless, we acknowledge the limitations of our selection and we have been investigating other factors for future inclusion, such as diversity land use mix and regional accessibility. However, more important than being complete in our analysis is to support JTC's urban planners in developing acceptable scenarios or providing arguments to have these scenarios accepted by higher management. As such, we need to balance research and practice, informing our approach from research but adhering to a practical aim.

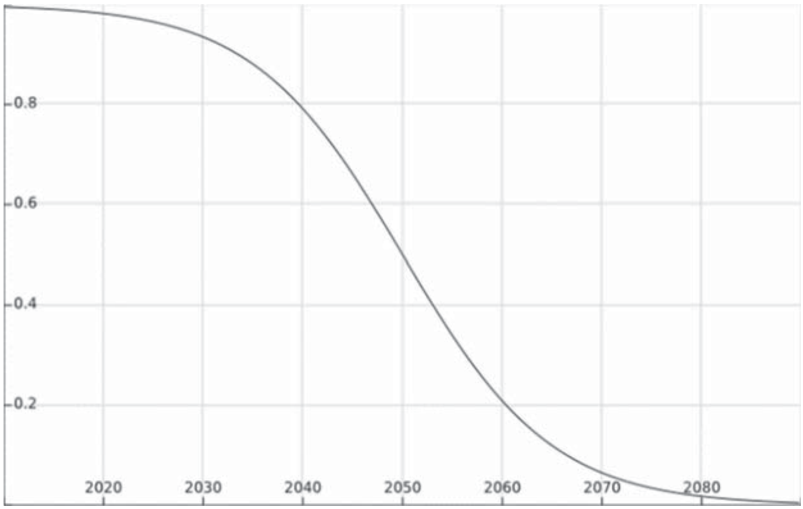
Land Availability

Land availability is affected by land leases, appropriation of land for other than industrial purposes, land reclamation and health and safety buffers. In Singapore's latest Master Plan, dating from 2014, most of the land within JIE is assigned as property type Business 2 (B2) for general (as well as light) industrial use (Figure 09.2). A small portion of JIE is assigned different property types, including residential, commercial, park, waterbody, civic & community institution, utility, reserve and special use. For the sake of the case study, we accept all other property types as fixed and limit the generation of planning scenarios to land currently assigned as B2 (and B1), as this is the land currently managed by JTC, while considering adjacency relationships to other land with different property types.

As industrial use is acknowledged to cause noise and smell nuisance, B2 assumes a nuisance buffer of 100m, that is, no residential (or similar) developments can take place within a 100m distance from a B2 property type. This condition is commonly resolved by separating both uses by a major or minor arterial road that is sufficiently wide. In addition, industries may be required to implement nuisance controls to ensure the 100m buffer is sufficient. Next to nuisance buffers, specific industries may require health and safety buffers to be imposed. Health buffers are mainly related to industries with exhaust fumes from incineration or other industrial processes and result in height restrictions to ensure no developments exceed the height of the exhaust within the stated buffer. Safety buffers, on the other hand, relate to the risk of hazards or incidents that may affect a larger area, such as explosions or the accidental release of toxic chemicals. Safety buffers will be imposed based on risk and impact assessment, but may be updated after a specific incident demonstrated the need for a larger buffer. In principle, safety buffers must be entirely contained within the plot assigned to the industry. Safety buffers can be related to lease ends, because the buffer would disappear once the industry has ended its operations or has moved elsewhere.

Finally, land reclamation is treated similar to land leases with the date of completion of the reclamation activity as the lease end date. The current property type, before land reclamation is completed, is considered as Waterbody. Future appropriation of land for other than industrial purposes, e.g., future green or waterbodies that are being conceived as part of the scenario development, can be treated oppositely, with a start date for the appropriation and a future property type, after the appropriation. In the analysis of urban potentiality, however, we consider these lands as not available.

In principle, land availability is measured at a point in time. However, for the sake of assessing urban potentiality, we are adopting an analysis over time, using a sigmoid function to transform a point in time into a value between 0 and 1, where 0 means no availability at all and 1 means immediate availability. Because 2050 is considered as the target date, we consider 2050 as the inflection point (Figure 09.3) and 2010-90 as the primary range (all current lease ends predate 2070) for the sigmoid curve. When applied to lease ends, any lease ending before 2050 will result in a value greater than 0.5, while any lease ending after 2050 will result in a value less than 0.5. We apply this analysis to lease ends as well as to safety buffers, acknowledging that safety buffers relating to plots are also bound by these plots' lease ends. Overall, land availability is considered impacted by lease ends and safety buffers ending in time. The final value for land availability is determined as the minimum of the values of either analysis, as both should be read as restricting availability.



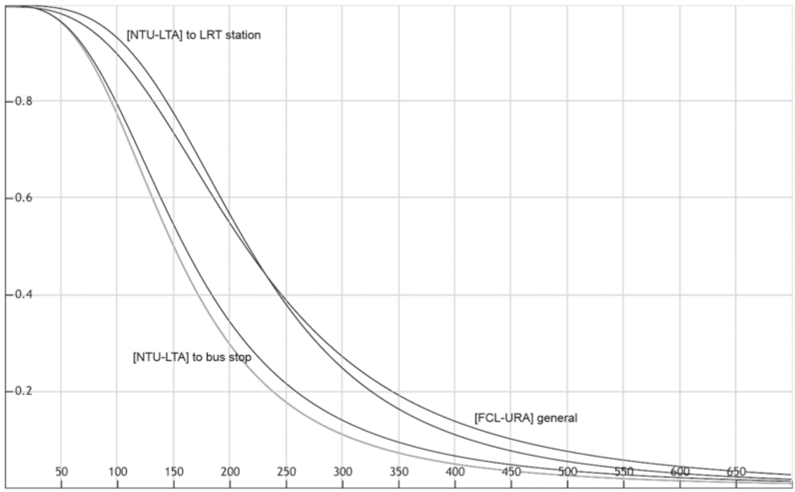
$$y = 1 - \frac{1}{1 + e^{\frac{2050-x}{7.5}}}$$

Figure 09.3

The sigmoid function transforming points in time into the range 0 to 1 (source: fooplot.com).

Accessibility to Transit

Transit planners generally consider a walkable distance of 400m. However, studies on average walking distances in different cities have resulted in varying averages and correlations between walking distances (to bus stops) and the percentage of people (transit users) walking at least this distance. A survey study conducted in Singapore revealed an average walking distance of 187m to bus stops, 226m to Light Rail Transit (LRT) stations and 608m to MRT stations[8]. While these distances are measured over actual walkways, in the context of future urban developments, we must instead use straight-line distances and reduce these averages accordingly. We adopt the assumption that in a porous area or over a well-connected grid, the straight-line distance may be about 80% of the actual walking distance. Furthermore, we omit the distinction between bus stops and LRT stations and use curve-fitting to deduce a function that can transform distances into accessibility values between 0 and 1. Simplifying the exponent values in the functions, we arrived at a general function of probability=1/(1+(distance/average)^3) with an average walking distance for bus stops of 150m and for MRT stations of 450m (Figure 09.4).



$$y = \frac{1}{1+\left(\frac{x}{150}\right)^3}$$

Figure 09.4

A comparison of the adopted function (highlighted in orange) transforming distances to bus stops into probabilities within the range 0 to 1, with fitted curves derived from two Singapore studies: an NTU-LTA study[8] and an FCL-URA study[9]. Note that the latter is a general walkability study conducted in the CBD (source: fooplot.com).

Overall, accessibility to transit is a combination of accessibility to pick-up/drop-off points for different modes of public transportation. Here, we distinguish between trunk buses and feeder buses and acknowledge a preference of MRT over trunk and feeder buses, beyond the distinction in average walking distance. Therefore, we are adopting weights of 1, 0.75 and 0.5, for MRT, trunk buses and feeder buses respectively, with the final value for accessibility to transit as the maximum of all three values when multiplied by the respective weights. We acknowledge that these weights may seem rather arbitrary, however, we consider them as mere parameters that could be adjusted by the planner in an exploratory manner. In addition, we try to take into account future MRT lines, even if the location of the lines and stations is not yet known. Making appropriate assumptions, we distinguish projected MRT lines from existing lines and take into account the projected development timeframe and reduce the value at the ration of the number of years until operation over the number of years until about 2080 (considering 2050 as the half-way point between now and approximately 2080).

Presence of Green Spaces (and Waterbodies)

As is common in a location choice approach[7], we consider both the accessibility and the area of green spaces in the analysis. Walkable distance to parks generally depends on quality and amenities. As JIE currently contains very few green spaces and any existing parks will likely be redeveloped, we consider a conservative measure of accessibility by adopting the same 150m radius for (projected) green spaces as we have done for bus stops.

For areal measurement, we consider a well-connected neighbourhood as the basis with an 800m walking distance or a 640m radius, and measure the total green area within this neighbourhood. Once again, we adopt a sigmoid function to normalise the area within the range of 0 and 1. With a few exceptions, most large recreational parks in Singapore have an area of around $0.5km^2$ to $0.6km^2$. Tentative plans for the development of new or expanded green spaces within JIE corroborate this result. As such, we have selected $0.25km^2$ as the inflection point of the sigmoid curve. Note that the total area of a neighbourhood with 640m radius is almost $1.29km^2$.

Projected green spaces may include both recreational parks and stretches of greenery, the latter lining up selected coastlines, river banks, existing or projected canals, and minor arterial roads. For this reason, we take both parks and greenery into account with respect to accessibility, while only the former contributes to the areal analysis. As such, when combining both analyses under a weighted sum, the greenery will play a minor role with respect to the parks. As a default, we consider a 50/50 weighing of accessibility and area of green spaces, though these weights can be easily adapted by the planners.

While the same analysis may apply to waterbodies, very few waterbodies in JIE are accessible to the public. Most of the coastline is not and while some parts may be considered to be made accessible and be lined with greenery, most of the coastline is anticipated to remain industrial. Rivers and canals may similarly be projected to become accessible and be lined with greenery, while other waterbodies within or near JIE already form part of a park or are projected to be integrated into a park. As greenery is already considered as part of the green spaces' analysis, we omit a similar analysis of accessible waterbodies. Only for other kinds of analysis processes, such as industrial land sourcing, do we consider proximity to the industrial coastline as a potentially contributing factor.

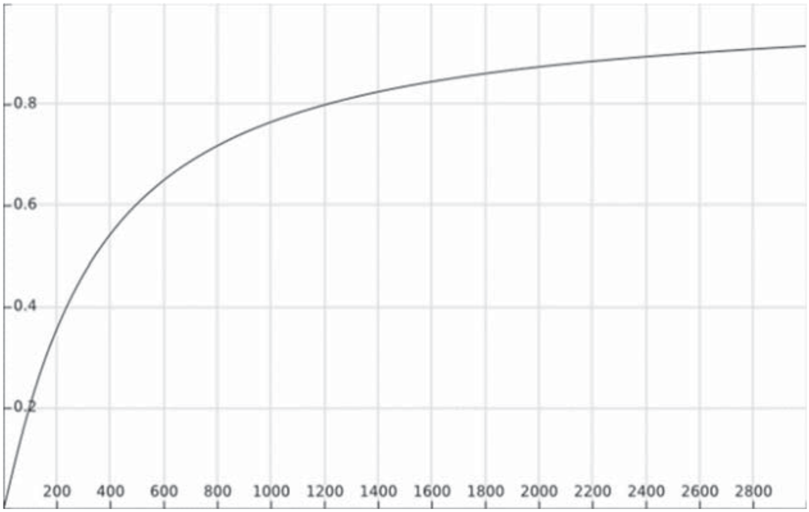
Presence of Industry

The presence of industry is commonly considered to negatively impact residential location choice[7]. Next to the share of industrial land use within the neighbourhood, the proximity of industry may also be considered in this assessment. It is well known in Singapore that people prefer not to live within visual proximity of industrial buildings. While the visual recognition of their industrial character and their aesthetics may play a role, and thus may allow for some alleviation through design, it remains important to consider their presence as an influencing factor. Considering that a 100m nuisance buffer is commonly established by the dividing presence of an arterial road, we may consider a distance of at least 300m through the adoption of a sigmoid function with inflection point at 150m. In addition, we can apply the same areal analysis for industry as for green spaces, obviously with an opposite impact.

When focusing on identifying potential urban nodes, we actually omit the presence of industry and refer instead to the land availability analysis. While the presence of industry with respect to land availability does not impact the surrounding area, except in the case of safety buffers, the cumulative, aggregate urban potential over a "neighbourhood" with 640m radius (see section 1.6) does expand the impact of present industry over its surrounding area.

Exposure to Traffic Noise

Another negative impact is exposure to traffic noise. As it is very hard to anticipate the impact on traffic volume as a result of urban developments in JIE, we are mainly concerned about the expressway running through the estate. Lau *et al.*[10] report on a road traffic noise study conducted for the same expressway though at a point outside of JIE. Measuring hourly traffic flows, % of heavy vehicles and mean traffic speed from 6:00 until 24:00, they used the commonly adopted CRTN method to predict an L10(18h) level of 73.5 dBA. In addition, they measured the road traffic noise level at 15m from the nearside edge of the road and 1.2m above the ground, resulting in an L10(18h) level of 70.0 dBA. Additionally, we should note that at the measuring location, the expressway is an 8-lane city-level highway with heavy traffic flows, including commuter traffic (% of heavy vehicles measured reached a highest value of 24.6 (14:00) and a lowest value of 13.3% (23:00)). Instead, throughout JIE, the expressway is mostly a 6-lane highway either at ground level or at overpass level, with much fewer commuter traffic and, thus, a higher percentage of heavy vehicles. As such, we consider the measured value of 70 dBA as guiding. Using a predictive tool[11], we approximated the expected distance for a reduced noise level of 50 dBA at about 340m. Considering that further reductions of the noise level require ever larger distances, we selected 340m as the half-way point (y=0.5) and a low exponent of 1.1 (Figure 09.5).



$$y = 1 - \frac{1}{1+\left(\frac{x}{340}\right)^{1.1}}$$

Figure 09.5

The adopted function transforming distances to the expressway within the range 0 to 1, guided by measured and predicted noise levels (source: fooplot.com).

Aggregate Analysis

To determine urban potential, we first consider the aggregation of four of the five aspects considered above: land availability, accessibility to transit, presence of green spaces and exposure to traffic noise. The aggregation is achieved by summing the weighted outcomes of these four analyses (Figure 09.6 and 09,7). The actual weights should be considered as parameters for the planner to play with.

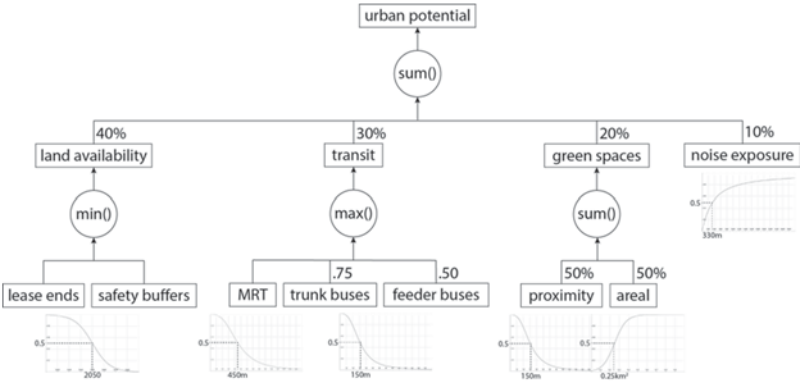


Figure 09.6

The aggregate analysis for urban potential. The respective weights should be considered as parameters for the planner to play with.

Urban nodes necessarily need a critical mass. For this reason, we additionally compute for each grid cell a normalised cumulative urban potential over a “neighbourhood” with 640m radius about the grid cell. This accumulation will favour areas with consistently high values, rather than peak values surrounded by much lower urban potential. In order to normalise the result, we can divide the cumulative urban potential value by the summed area of all grid cells within the neighbourhood. Unfortunately, this favours smaller boundary areas which may include a relatively higher number of near-peak values. For this reason, we consider dividing the cumulative urban potential value by the weighted sum of, on the one hand, the actual neighbourhood area as the summed area of all grid cells and, on the other hand, the maximum neighbourhood area, π * 6402. Using weights of 2/3 and 1/3, respectively, presented us with a more balanced result.

Discussion

From the cumulative urban potential, urban nodes could be selected automatically as centred on cells with the highest cumulative urban potential values. The size of the urban node or growth area could subsequently be deduced from the aggregate urban potential through sampling. However, as urban nodes should be some minimum distance apart, selecting urban nodes would be an iterative process of selecting the highest cumulative value, determining, the radius of the urban node from the landscape of aggregate values, then excluding a buffer area (with a minimum radius of twice the radius of the urban node), before selecting another node, etc. However, we argue that this selection process should not be automated and should, instead, be left to the urban planners, based on both the aggregate and cumulative urban potential, any other information generated from the methodology here described and, of course, other information the urban planners may deem relevant or appropriate. In this light, the automated quantitative approach can be used as an exploratory means to identify urban potential and understand the impact of the different aspects with respect to this potential, and as a providing some objective underpinning that can serve as arguments to support the decision-making process on the location of urban nodes.

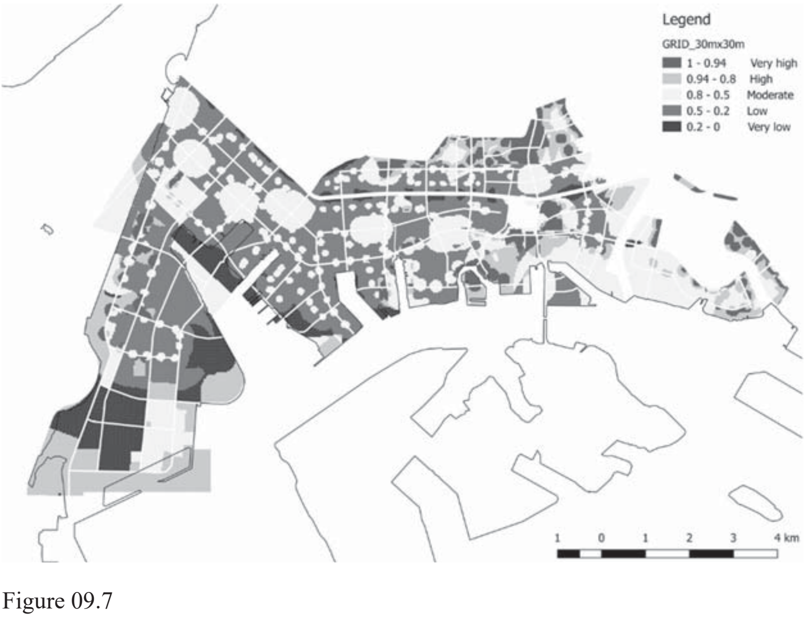


Figure 09.7

The result from the aggregate analysis for urban potential.

Once the selection of urban nodes has been made, this selection, in turn, serves to guide the land use and density planning that will serve to influence the future Master Plan. The computational support to this planning process will follow a similar approach of location choice and aggregate analysis, although the analyses will be time dependent and differ both in the analyses, including urban catchment, and the aggregation.

Conclusions

We have presented a methodology for computational analysis of the potential for the development of urban nodes within an industrial estate in order to transform the estate into a major catchment area for future population growth. We adopted a location choice approach, considering land availability, accessibility to transit, presence of parks, presence of industry and traffic noise exposure as influencing factors. The aggregation of the analyses is considered as a weighted sum, with the potential for the urban planners adopting the methodology to play with the weights. The selection of urban nodes proceeds from a normalised cumulative urban potential calculated over a neighbourhood area.

Acknowledgements

This work received funding support from NUS-JTC i^3 Centre. We would like to thank the Urban Planning Department of JTC, under the Deputy Directorship of Aloysius Iwan Handono, for their invaluable support.

References

1. Shereen Tay. Urban planning framework in Singapore. SingaporeInfopedia, National Library Board, 2008. http://eresources.nlb.gov.sg/infopedia/articles/SIP_1565_2009-09-09.html. Last accessed: 5 February 2018.
2. Urban Redevelopment Authority. About the Concept Plan. https://www.ura.gov.sg/Corporate/Planning/Concept-Plan/About-Concept-Plan. Last accessed: 27 February 2018.
3. Urban Redevelopment Authority. Concept Plan 2011 and MND Land Use Plan. https://www.ura.gov.sg/Corporate/Planning/Concept-Plan/Land-Use-Plan. Last accessed: 27 February 2018.
4. Department of Statistics, Ministry of Trade & Industry. Population Trends, 2017. http://www.singstat.gov.sg/docs/default-source/default-document-library/publications/publications_and_papers/population_and_population_structure/population2017.pdf. Last accessed: 5 February 2018.

5. Land Transport Authority. Cross Island Line. https://www.lta.gov.sg/content/ltaweb/en/public-transport/projects/cross-island-line.html. Last accessed: 27 February 2018.
6. Land Transport Authority. Jurong Region Line. https://www.lta.gov.sg/content/ltaweb/en/public-transport/projects/jurong-region-line.html. Last accessed: 27 February 2018.
7. Patrick Schimer, Michael Van Eggermond, Kay Axhausan. The role of location in residential location choice models: a review of literature. The Journal of Transport and Land Use 7(2) (2014), 3-21.
8. Piotr Olsewski. Sony Sulaksono Wibowo. Using Equivalent Walking Distance to Assess Pedestrian Accessibility to Transit Stations in Singapore. Transportation Research Record: Journal of the Transportation Research Board 1927 (2005), 38-45.
9. Alex Erath. Michael Van Eggermond. Sergio Ordonez, Kay Axhausen. Modelling for Walkability: understanding pedestrians' preferences in Singapore. In Proceedings of the 14th International Conference on Travel Behavior Research, Windsor, UK, 19-23 July 2015.
10. Siu Yu, Stephen Lau, Ji Zhang, Siu-Kit Lau Hongzhan Lai. A Comparative Study of Road Traffic Noise based on Measurement, Prediction and Simulation according to the CRTN Method in Singapore. In Proceedings of the 9th Cross-Strait Acoustic Conference, Macau, China, 11-12 August 2016.
11. Calculation of road traffic noise according to the 2002 version of the Dutch calculation method. https://rigolett.home.xs4all.nl/ENGELS/vlgcalc.htm. Last accessed: 26 January 2018.

CHAPTER TEN

CIRCUMSTANCES GENERATE THE FORM: ORIGIN AND EVOLUTION OF THE HOSPITAL PAVILION TYPOLOGY

SÉRGIO MENDES

Introduction

In this paper we try to analyse the origin and the evolution of the typology of the pavilion hospitals, a very efficient typology, not only to solve the problems that led to its emergence, but also because it is versatile enough to have been used in buildings with other functions over time, specifically in various universities that we present in the second chapter. Instead, we display the plans of the buildings, we chose to present schemes without scale, drawn by the author, since they clarify the issues we wish to emphasise, which are the way the pavilions relate to each other and how they relate to the main circulation zones. Schemes shall be interpreted from the legend shown in Figure 10.1. It should be noted that, in these schemes, we tried to simplify the representation of buildings, eliminating those that stand out from the main building, to point out the aspects that seem most important. The plans of the buildings themselves can be found from the links in the bibliography. We also warn that we have only studied orthogonal hospital pavilions, excluding those of other types, namely the cruciform type, because this typology was not generally applied in buildings with functions other than hospitals and prisons, and even these, only in specific periods.

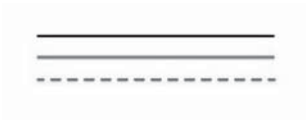


Figure 10.1

Black line: building boundary
Continuous red line: main interior circulation zones.
Discontinuous red line: covered main exterior circulation zones.

Origin of the Hospital Pavilion Typology

In 1772 it burned the *Hôtel-Dieu*, the medieval hospital with worse reputation of Paris.[1(1)] At that time, the conditions of hygiene and basic medical and sanitary care of the hospitals of this city were terrible, being ordinary join patients with beggars, orphans, and the blind. The fire generated the opportunity to discuss how the new hospitals should be built[2]. An important contribution to this discussion was the publication, in 1788, of the *Mémoires sur les Hôpitaux de Paris*, by M. Tenon (1724/1816), a distinguished surgeon and member of the *Societé de L'École de Médicine* of Paris, where he reported the terrible conditions to which the patients were subject at *Hôtel*-Dieu,[3] raising the hypothesis of dismemberment of hospitals and separation of patients.[3] This publication was partly the result of a visit to a number of hospitals, particularly in the UK, of a French commission consisting of Tenon himself and his colleague Charles-Augustin de Coulomb (1736/1806) who moved in 1787, to this country, to visit these institutions. This commission, created in 1777, also opened a public architectural competition, having received numerous proposals.[4]

Thomas Markus, in his treatise *Buildings & Power*, said that a building, which pleased the commission during his visit to the UK, was the *Royal Naval Hospital of Stonehouse* (1756–64), in Plymouth, designed by the architect and military Alexander Rowehead[5]. In fact, at the time, there was already the conviction that the causes for high mortality at the *Hôtel-Dieu Hospital* were the lack of ventilation of the building, aggravating the spread of contagious diseases.[1(2)] The *Royal Naval Hospital of Stonehouse* seemed,

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[1] The *Hôtel-Dieu* in Paris was a non-specialised medieval hospital. At the end of the Middle Ages, it had approximately 450 beds and 1280 patients, meaning that there were, on average, three patients per bed, without discrimination of type of disease. The mortality, as can be estimated, was enormous.
[2] Pevsner, N. *Historia de las Tipologias Arquitectonicas*, op. cit., p. 180. In fact, the simple conditions in which patients remained in this hospital were more than

given its typology, to solve this problem. This hospital forms a U-shaped complex, partially enclosed at the end where the quadrangle is accessed, with a church and ten pavilions with three floors, interspersed with four smaller ones and joined by a covered outdoor gallery (Figure 10.2).

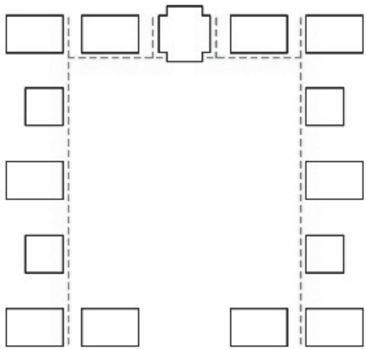

Figure 10.2

Schematic diagram of the *Royal Naval Hospital* of Stonehouse.

As can be seen, the typology of this hospital allowed solving several problems. At the origin of his layout was surely, as Markus[5] points out, Rowehead's military training. Like tents in a military camp, this hospital was organised in pavilions separated from each other, although united by the outer gallery, thus avoiding the spread of contagious diseases and ensuring an adequate ventilation between the buildings. Also, among the projects received in the competition launched by the commission was one that followed the same principle, although the pavilions were arranged differently. It was the design of Jean-Baptiste Le Roy (from 1777, though only published in 1789), which featured a U-shaped solution containing on each side eleven large pavilions (Figure 10.3). Particularly interesting was the justification set out in the project description. In this, Le Roy referred to

sufficient for mortality to reach the very high numbers that Pevsner reports from various authors. In addition to the lack of hygiene and health conditions already mentioned, and to live an average of three patients in each bed, without discrimination of disease, there were situations that were absurd. In the operating rooms, for example, the patients who were to be operated on the next day, those who were going to be operated on that day, and those who had been operated on the day before, went out together.

rooms arranged as tents in a field, totally isolated and surrounded by permanently renewed air.[2]

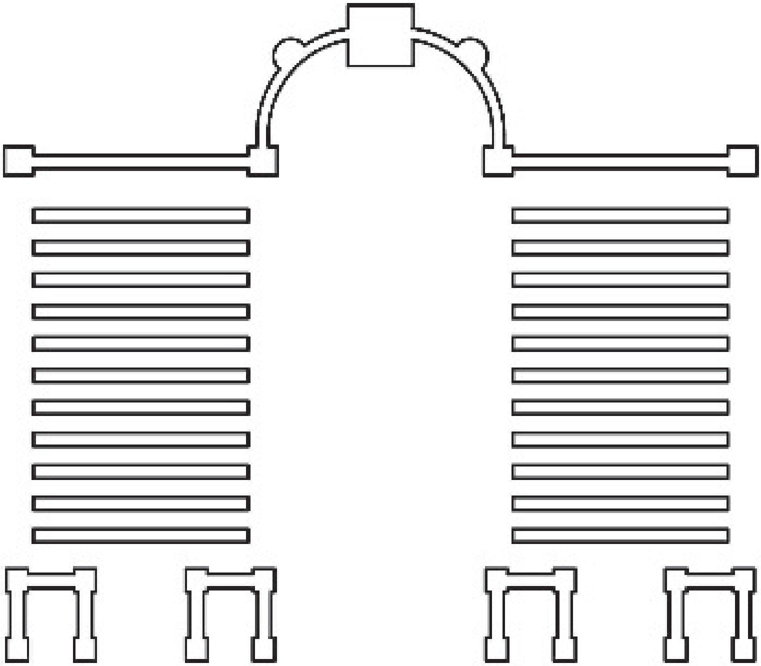

Figure 10.3

Schematic diagram of Le Roy project for a hospital.
Note: Main circulation zones are not indicated because they are not clearly visible in the project to which we have had access.

Although it was a utopian project and had a very classical composition, this project immediately raised the hypothesis of systematising the layout of the pavilions, being an important precedent for what became one of the typologies adopted in pavilion hospitals.

It is not surprising that a proposal for a hospital (1788), designed by Bernard Poyet (1743/1829) and by M. Tenon himself that, although it was conceived isolated and enclosed in itself, it somehow condensed the idea of what should be, for these authors, a pavilion hospital (Figure 10.4).

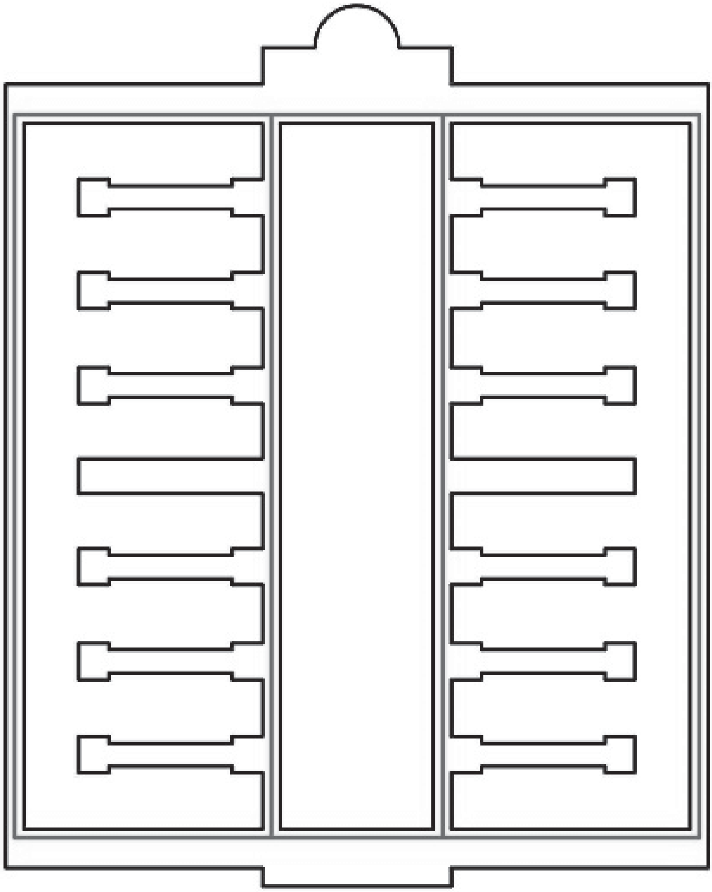

Figure 10.4

Schematic diagram of Poyet and Tenon project for a hospital.

The first hospital pavilion built in France, after the second cholera pandemic in Paris, was the *Lariboisiére Hospital* (1839/54), designed by Martin-Pierre Gauthier (1790/1855): "a complex whose typology derives directly from the Poyet and Tenon project, with a large central courtyard, around which is the corridor that gives access to all the pavilions, organised perpendicular to this"[6] (Figure 10.5). The hallway has a single floor, and the pavilions are three stories high.

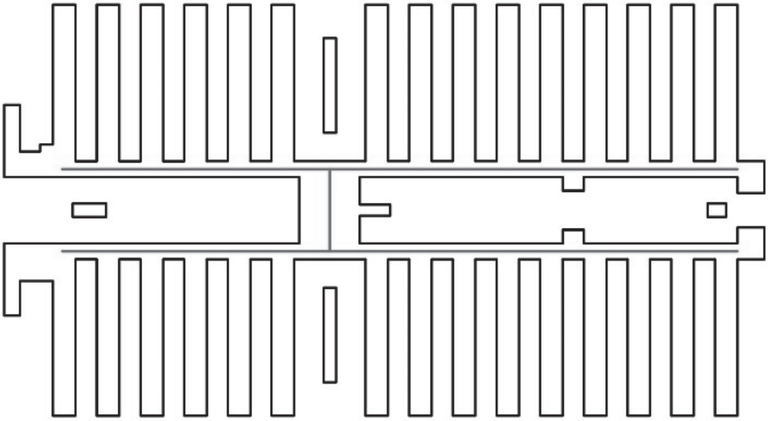

Figure 10.5

Schematic diagram of the *Satterlee General Hospital* plan.

The schemes of organisation of the plants we have seen so far are similar. The central quadrangle confers dignity to the complex and ensures the illumination of the main circulation areas, which develop around it. The buildings are perpendicular to the quadrangle, ensuring efficient lighting and ventilation of the pavilions.

Evolution of the Typology of Pavilion Hospitals

In the context of the American Civil War, it was built in 1862 by the Army, in Philadelphia, under the guidance of Dr. Isaac Israel Hayes (1832/1881), the largest hospital to receive the wounded from the war, the *Satterlee General Hospital*, which had more than seventeen thousand beds, in pavilions mostly on a single floor. The typology used, based on the scheme of the pavilion hospitals that we have seen before, shows that, in case of need and smallness of the available land, it is possible to profit from the occupation of the soil, here taken to a great extreme, as can be seen in the scheme represented in Figure 10.6.[7]

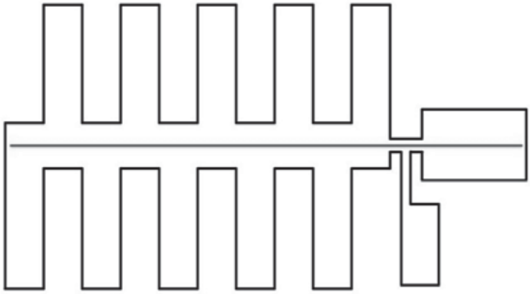

Figure 10.6

Diagram of the *Judiciary Square Hospital* plant.

In 1861, before the construction of the *Satterlee General Hospital*, the *United States Sanitary Commission*, always in the context of the American Civil War, had already suggested to the government the construction of pavilion hospitals to receive the sick and wounded. One of the first hospitals built on this principle was the Judiciary Square Hospital (1862/65), in Washington (Figure 10.7). The main problem of this hospital was the ventilation that proved to be insufficient, largely due to the fact that it is a compact building, mostly of a single floor, joined by a central corridor, which made it difficult to isolate patients, leading to the spread of diseases.[8]

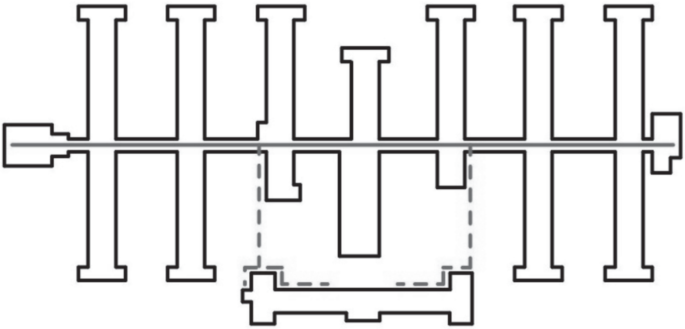

Figure 10.7

Diagram of the *Herbert Hospital* plant.

As you can see, this is a variant of the scheme of buildings we have seen so far. We can thus designate the first typology presented by pavilion hospital in double band (PHDB) and that of the *Judiciary Square Hospital* by Linear Pavilion Hospital (LPH).

This same LPH typology was also used in the UK by Sir Douglas Galton (1822/1899), in the design of *Herbert Hospital* (1865), renamed *Royal Herbert Hospital* in 1900, located in Woolwich, London (Figure 10.8). This hospital, created to welcome the wounded from the Crimean War, was based on the ideas of Florence Nightingale (1820/1910), who was familiar with Galton, seeking to treat patients by creating ideal conditions of pure air, natural light and controlled temperature.[9] The hospital pavilions were three stories high as the height of the central corridor varied.

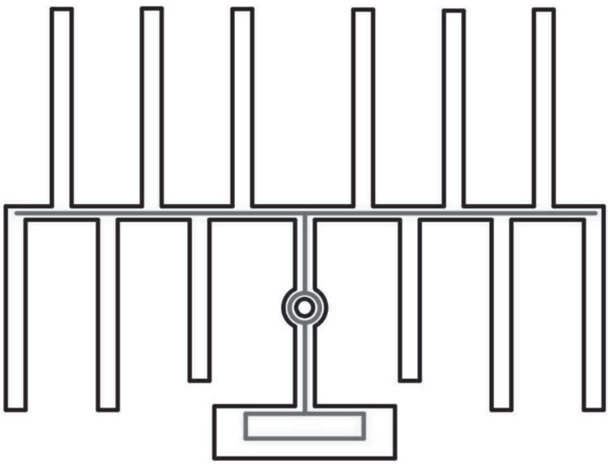

Figure 10.8

Diagram of the Hospital for the *Comando de Puerto Principe* plant.

The LPH typology has become widely used in many types of hospitals, especially in the new world. It is interesting to note that the solution allows different types of organisation of the pavilions. In the *Judiciary Square Hospital,* the pavilions are alternated with each other, as they are located on each side of the central corridor, which does not happen at the *Herbert Hospital*, where the pavilions are aligned with each other.

In 1885, the project for a military hospital for the *Comando de Puerto Principe*, in Haiti, the alternating configuration of the pavilions will appear again, with a single floor height (Figure 10.9). But, in the case of *Herbert Hospital*, or in the project for Puerto Principe, the administrative building stands out from the hospital complex, conferring a street front with the dignity that, at that time, could not be attributed to the tops of the pavilions. In the case of the project for Puerto Principe, Henry Mazorra Acosta emphasises the location of the chapel, located in the middle of the gallery that links the main building to the corridor that serves the pavilions and which, according to this author, is a sign of the ecclesiastical origins of the nineteenth-century hospitals.[10]

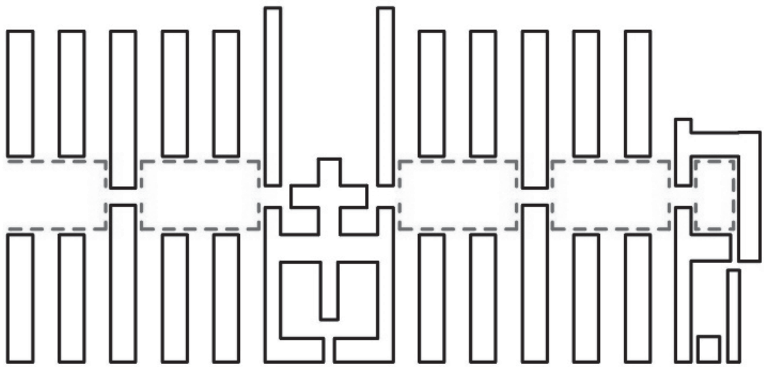

Figure 10.9

Schematic diagram of the Hospital of *Saint Vincent de Paul.*

The *Saint Vincent de Paul Hospital* in Santiago de Chile, which looked after leprosy and tuberculosis patients, was built in 1872 according to the design of Eusebio Chelli and Karl Ernst Stegmöller (the men's wing and the chapel); it was enlarged between 1888 and 1895 according to the design of Juan Geiger (the women's wing) using the PHDB double band solution, although forming several patios (Figure 10.10), in pavilions two floors high. It is again a solution with a high density of land occupation, resulting from the needs of the time and the size of the available land.[11]

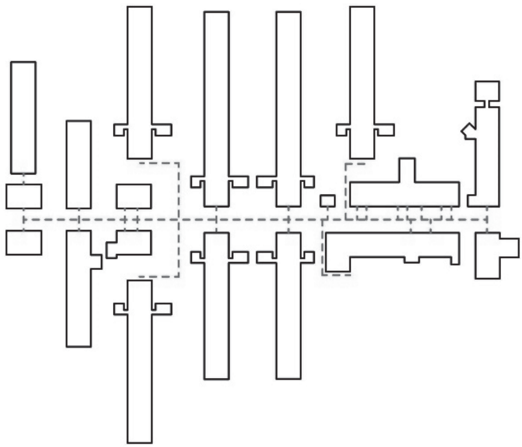

Figure 10.10

Schematic diagram of *Welsh War Hospital* plant.

Another hospital, built in 1914 to receive the wounded of the First World War, the *Welsh War Hospital*, in Netley, U.K. (Figure 10.11), designed by Edwin T. Hall (1851/1923) and E. Stanley Hall (1881/1940), presents the linear scheme LPH, but with a single floor pavilions isolated from each other, although united by a covered outer gallery. This scheme demonstrates the possibility of the independence of the pavilions and the versatility of the possibility of accessibility to them.

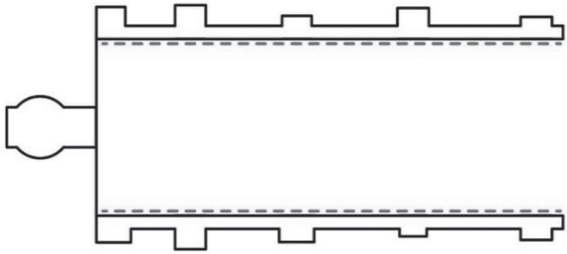

Figure 10.11

Schematic diagram of the central nucleus of the campus of the *University of Virginia*.
Note: The pavilions, 5 in each band, appear interspersed with the students' rooms.

Other hospitals could be presented but not within the scope of a single paper. We can for the examples presented verify the versatility of buildings and pavilion complexes. Both the PHDB and LPH schemes allow for the independence of the pavilions and, by extension, the functions of the various building bodies, ensuring a high efficiency in the density with which they ensure the occupation of the ground when this is imperative.

It should be borne in mind that, in 1972, in the seminal book Urban Space and Structures, more specifically in “speculation 4”,[12] Leslie Martin and Lionel March found, when analysing the most efficient forms of land occupation, that the construction in band, in the same conditions of illumination and height, had twice the capacity of occupancy of the soil than the isolated constructions.

The Use of the Typology of Pavilion Hospitals in the Universities

For the above reasons, it is not surprising that these typologies have been used in other kind of buildings, namely in universities. The pioneer was surely Thomas Jefferson (1743/1826)[2], in the plan he developed for the University of Virginia, in the USA[13] (Figure 10.12), built between 1817 and 1825, before the construction of the *Lariboisiére Hospital* in Paris (1839/54). The central nucleus of the university consists of 10 pavilions with two floors intended, in the lower floor, to the classrooms and, in the upper, to the dwellings of the teachers. Between the pavilions are the rooms of the students and, in the centre, is located the library of the university. The route between buildings is through covered outer galleries and the central space is a huge lawn, of great significance on a campus of an American higher education institution.

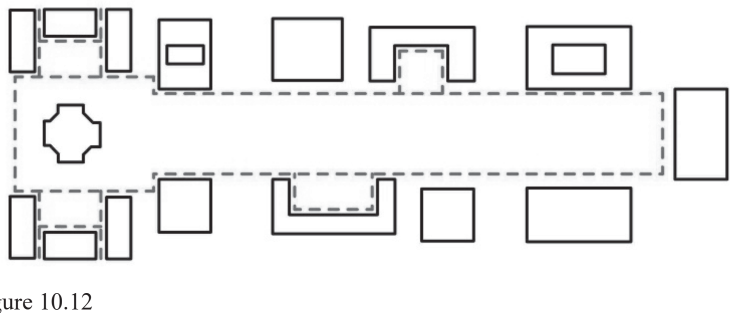

Figure 10.12

Schematic diagram of St. Thomas University campus plan.

In 1957 Philip Johnson was inspired by Jefferson's project for the University of Virginia when he drafted the plan for the University of St. Thomas in Houston, Texas. The big difference is that Johnson's plan included the construction of a two-storey passerelle, designed and built from the start to prevent changes to his plan[14] and the passerelle encloses the central space (Figure 10.13).

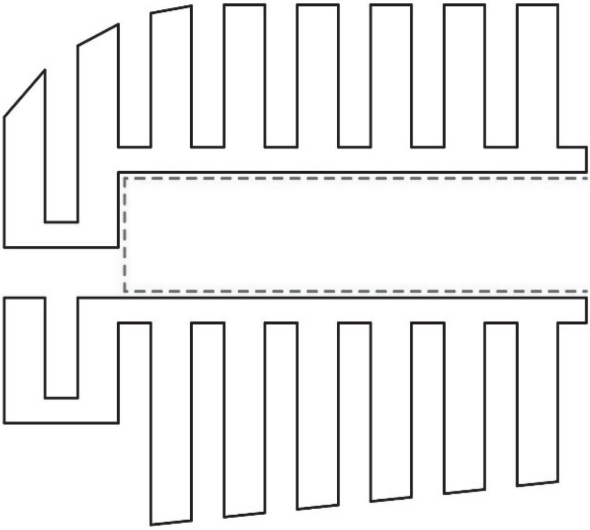

Figure 10.13

Schematic diagram of the Master Plan of the *South Departmental Expansion Zone* of the University of Aveiro.

It was elaborated on in the *Review of the Master Plan of the University of Aveiro* (1987–89) by a team from the Centre for Studies of the Faculty of Architecture of the University of Porto led by Nuno Portas. The University of Virginia created the model used to design the South Departmental Expansion Zone[14] (Figure 10.14). This was a case in which there was an enormous need to make land occupation profitable, because the university needed to ensure the possibility of building a large number of departments, the available space was relatively small and Nuno Portas intended to equip it with a central space that would confer dignity to the University and which is, today, surely the most monumental space in the city of Aveiro. In order to achieve these objectives, Nuno Portas resorted to the previously mentioned studies of Leslie Martin and Lionel March.[15]

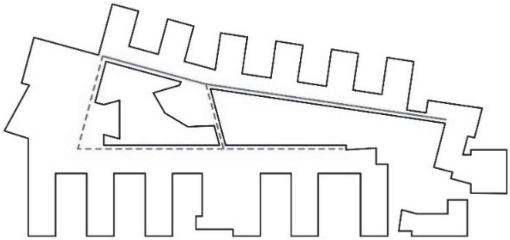

Figure 10.14

Schematic diagram of the *Faculty of Engineering* of the University of Porto.

With the need to build three-story high-rise buildings, he explored the possibility of concentrating construction on the outskirts of the land. The buildings were approximated as much as possible, within the proper ventilation and lighting conditions, which solved the university problem. Also, for the Pedro and Luís Ramalho project for the Faculty of Engineering of the University of Porto (2001), also in Portugal, was used a scheme similar to that of the University of Aveiro, naturally conditioned by the available land, which forced an inflection of one of the wings (Figure 10.15). Being a large complex with about 8000 students and approximately 550 teachers, it was precisely the organisation following the PHDB typology that allowed to accommodate the facilities, although in this case with buildings mostly four stories high.

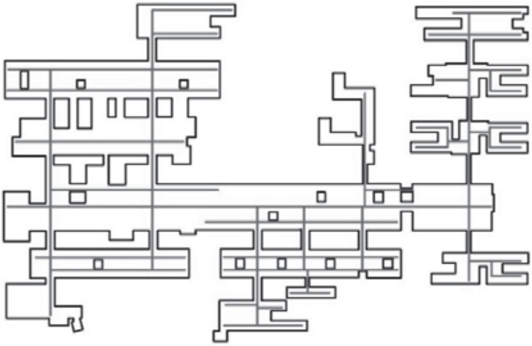

Figure 10.15

Schematic diagram of the *University of Odense.*

It is also worth mentioning the case of the University of Odense in Denmark, project by Holscher, Krohn, and Rasmussen (1971), in which the scheme is different. If in the previous cases the complexes were constructed according to the PHDB typology, in this case it is a variation of the LPH typology. It is a single building with two storeys high and, at bottom, its typology corresponds to a variation of that of the *Welsh War Hospital* in which, as was common in several new western universities in the sixties and seventies of the last century, sought to aggregate all departments into a single building, constructing mega-structures for higher education (Figure 10.16). The solution demonstrates how it is possible to aggregate several pavilions forming a mesh that allows a phased construction of several types of complexes with varied functions, performed according to the needs and the funds available at any moment.

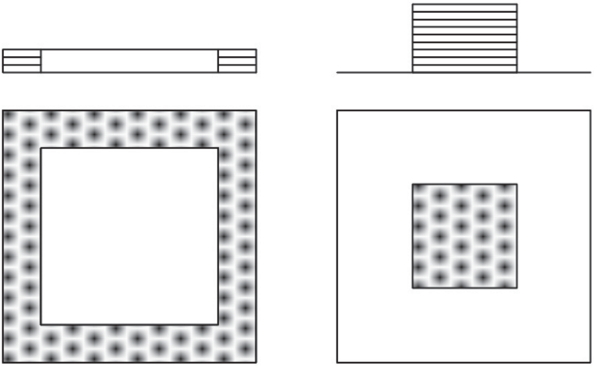

Figure 10.16

Demonstration of speculation by Martin and March: The buildings in the left figure cover exactly the same area as the building on the right.

Conclusions

As we have seen, the problems resulting from the poor conditions of medieval hospitals and the need to avoid the spread of contagious diseases have led to the typology of pavilion hospitals. We can therefore conclude that, indeed, the necessity led to the shape, or if we prefer, to the configuration of these buildings, thus justifying the title of this paper.

We can also verify that the typologies of the pavilion hospitals are suitable for buildings or complexes of buildings, with functions different from those of hospitals, as is the case of the universities we have seen. It matters, however, to re-invoke the question of the type of land occupation of some of the examples presented. In the context of large wars or epidemics, when the land was scarce and the need was great, the two typologies allowed the construction of complexes with great density of occupation of the soil, accommodating the enormous amount of wounded and sick.

As we have already mentioned, Leslie Martin and Lionel March studied various forms of soil occupation, which are condensed in the book *Urban Space and Structures*, where they present several studies carried out at the Cambridge School of Architecture's *Centre for Land Use and Built Form*. The result of these studies proves that, in a given land, the choice between constructing a tall building in the centre of the ground or constructing buildings on the outskirts of the land, allows the construction of the same area, with the difference that, in the peripheral construction, we only need one third of the height of the isolated construction.[16] This means that, by exploring the peripheral construction of the ground, the interior of the soil can be released (Figure 10.17).

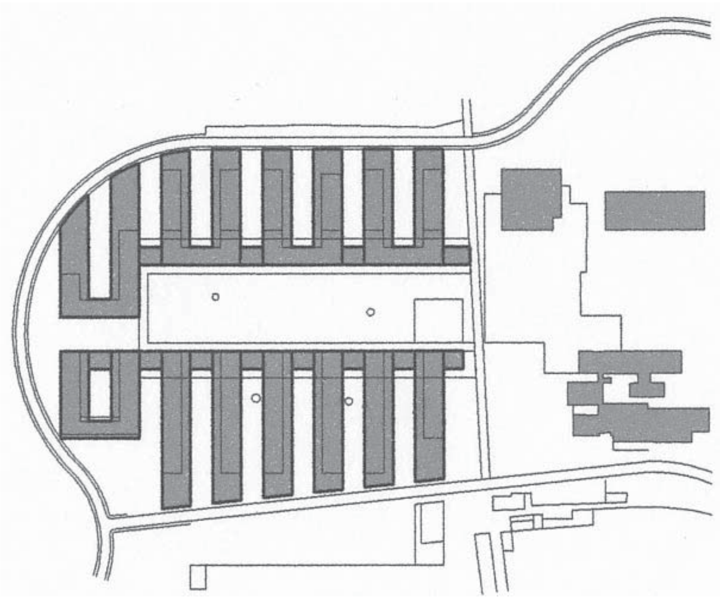

Figure 10.17

Demonstration of the maximum occupation that the plan of the University of Aveiro allowed, leaving the core of the ground free.

On one hand, applying the rule commonly used to define the heights of buildings—the distance between facades must be equal to the height of the buildings—we verified that the PHDB typology allows both a high density of construction and the maintenance of a large space inside the grounds, as is the case of some of the examples we have previously seen, namely that of the University of Aveiro. The LPH typology, on the other hand, allows the development of buildings articulating the pavilions, provided that a grid is used to ensure efficient circulation among them, such as the case of the University of Odense, allowing also a high density of construction, but occupying the space of the interior of the terrain (see Figure 10.16). Both types can be used in buildings of various functions. As this paper has been written for a symposium on formal methods in architecture, the challenge is that others, trying to find a suitable formal method, can systematise its study and predict new applications for these typologies.

References

1. Nikolaus Pevsner, Historia de las Tipologias Arquitectonicas (Barcelona: Gustavo Gili, 1980) page 168.
2. Sérgio Mendes "Thomas Jefferson e o Projeto da Universidade da Virgínia: Uma Investigação sobre a Tipologia do Campus" (Porto: CESAP, 2017) page 27.
3. M. Tenon Mémoires sur les Hôpitaux de Paris (Paris: Librairie de la Faculté de Medecine, 1788) page xix.
4. Quim Bonastra, Gerard Jori "El uso de Google Earth para el Estudio de la Arquitectura Hospitalaria (II): Hospitales Cruciformes, Radiales y Pabellonarios" in Ar@cne, Revista Electrónica de Recursos en Internet sobre Geografía Y Ciencias Sociales (Barcelona: ed. Universidad de Barcelona, 2009) 123, page 18.
5. Thomas A. Markus Buildings & Power: Freedom and Control in the Origins of Modern Building Types (London: Routledge, 1993) p118.
6. Cf. with the plan available in http://guardianoftheartifacts.blogspot.pt/2013/07/theres-exhibit-where-part-2.html.
7. Cf. Office of Medical History, available in http://history.amedd.army.mil/booksdocs/wwi/MilitaryHospitalsintheUS/introduction.htm, item 20, site consulted at 30/11/2017.
8. Cf. https://alchetron.com/Royal-Herbert-Hospital, site consulted at 30/11/2017.
9. Henry Mazorra Acosta. "El pensamento ilustrado y la Arquitectura del Hospital en Cuba durante el siglo XIX: utopías y realidades"

Anales del IAA (2014) 44 (2) p. 128. Site consulted at 05/02/2018 at https://issuu.com/gibelino/docs/141-661-1-pb.

10. Cf. with plant available at http://iglesiaspatrimoniales.cl/english-version/old-leper-house-history/, Site consulted at 30/11/2017.
11. Leslie Martin; Lionel March. "Speculation 4" in Urban Space and Structures (London: Cambridge University Press, 1972) pages 35-38.
12. Cf. Hilary Lewis, John O'Connor Philip Jonson: the architect in his own words. (New York: Rizzoli, 1994) page 146.
13. Sérgio Mendes A Revisão do Plano Geral da Universidade de Aveiro e a Construção do Campus de Santiago. (Valladolid: Doctoral Thesis, Departamento de Teoría de la Arquitectura y Proyectos Arquitectónicos, Universidad de Valladolid, 2014), pages 263-265.
14. Leslie Martin "The Grid as Generator" in Urban Space and Structures, pages 20-21.

CHAPTER ELEVEN

DIGITAL INEQUALITY: HOUSEHOLD COMPUTER ACCESS AS A DETERMINING FACTOR IN THE GEO-LOCALIZATION OF SOCIAL DIFFERENTIATION OF SPACE

SOFIA GARZA, AIDA ESCOBAR

Introduction

Background

Mexican researchers confirm that the Monterrey Metropolitan Area (AMM) has the greatest social differentiation of space (SDS) in Mexico, at the same time they agree the metropolis has the highest labour income rates in the country. The reviewed investigations (Schteingart, 2013, González and Villeneuve, 2007 and Aparicio, Ortega and Sandoval, 2011) agree that the AMM can be identify as the most favourable socio-spatial situation in Mexico due to its integration to the US economy, its restructuration as a pole of national economic development and its strategic position in the process of globalization.

A comparative study by Ariza and Solis (2009) have identified the MMA with the highest levels of residential socioeconomic segregation in Mexico, maintaining it as the most noticeable city in terms of income polarisation in comparison with other two urban areas studied (Puebla and Mexico City). Consequently, Contreras (2007) indicates that a globalised metropolis like the MMA will tend to intensify its socio-spatial division in later decades. Economic competitiveness has been successfully associated with socio-spatial distribution by the Chicago School (DESAL, 1969), and recognise tensions between four elements: population, technology, customs and beliefs, and habitat. The existence of tension between social groups regarding access to technology is considered a new form of socioeconomic exclusion called the digital divide, (CEPAL, 2010).

Problem Statement

The methodological review showed the studies of SDS based their evaluations in three of the four elements proposed by the Chicago School, integrating socio-demographic variables of income, migration and ethnic condition, level of education, occupation, family status and urban and residential consolidation, but have not integrated technology indicators and have kept the spatial relationship between the SDS and the digital divide unexplored.

The review also noted a scarcity of studies that depart from a research hypothesis and determine the spatial distribution of the two phenomena based on elements of geographical analysis. The central problem is that the existing assessments of SDS haven't take into account the changes generated in the social and productive organisation of the Information Society (IS), changes caused by the growing demand for information in the evolution of ICT at a global, regional, and local level (Katz and Hilbert, 2003).

Purpose

Seeking to demonstrate the territorial digital inequalities present in the MMA, this study answers the question:

Is there a relationship between the digital divide and the geographical localisation of the spatial differentiation in urban space?

Based on geostatistical methods, it is intended to know if the SDS is related to the access to and use of ICT, the type and intensity of said relationship, for which a positive correlation is hypothesised, meaning to a superior digital divide, larger social differentiation.

Rationale

Based on a methodological review of SDS evaluations and following the recommendations made by Economic Commission for Latin America and the Caribbean (CEPAL), a synthetic index of evaluation is constructed. The index seeks to conclude, at a descriptive level, if there is a significant correlation evidencing that SDS is related to the exclusion from digital technologies. Meaning, the phenomenon of the digital divide moves along with the SDS phenomenon.

Social Differentiation of Space

The social division of space is the territorial expression of the class structure or the social stratification (Schteingart, 2001), but it does not refer exclusively to them. Let's clarify that the operative concept of this research is the differentiation, but it is not conceptually separated from segregation, marginalisation or inequality. The differentiation will then be defined as the action and effect of differentiating from the other, (Schteingart, 2013). This differentiation is seen through changes in the urban fabric and its functions, with respect to occupation conditions, family characteristics, ethnic differences, or as it's the matter of this research, the access to and use of ICT that leads to the distinction of the spatial components of the territory.

Concerning the study of the social structure of space we selected the Theory of Social Areas (TSA) by Shevky y Bell (1955), enriched by the contemporary analysis of Brindley and Raine (1979), who technologically advanced the TSA implementing the statistical factorial analysis based on a geographic database. The authors developed a model called the social area to classify populations of census areas in terms of three constructs: social status, urbanisation and segregation, (see Table 1). The census area is used as a unit of analysis because it facilitates the division of the city into a mosaic of social universes. The hypothesis of this theory is that social areas contain individuals who share the same way of life and the same ethnic origin and who, in turn, differ in attitudes and behaviours of individuals living in another type of social area.

The three constructs of the social differentiation of space based in the Theory of the social areas of Shevky and Bell	
Construct	**Variable**
Social Rank (occupation)	occupation
	education
	income variables
Urbanization (characteristics of the family)	fertility
	female employment activity
	single family homes
Segregation (ethnic differences in space)	Variables of ethnic groups
	variables of the migratory condition

Table 11.1

Constructs and variables of the TSA (source: own elaboration based on Shevky and Bell, 1949 and Brindley and Raine, 1979).

The Digital Divide

The Organisation for Economic Co-operation and Development (OECD), (2001) frames the definition of the digital divide as the gap between individuals, households, businesses and geographical areas at different socioeconomic levels with respect to both their opportunities to access ICT and the use of the Internet for a wide variety of activities. For Norris (2001) it is a phenomenon that involves three aspects: the global gap (present between countries), the social gap (present within a nation) and the democratic gap (present between those who participate in public affairs online and those who do not). Regarding the quantitative aspects of the digital divide, Arquette, (2001) has highlighted the statistical differences in access to ICT according to a wide range of socio-demographic variables among which we can underline the level of income, schooling, race, ethnicity and place of residence. This research focuses on the study of the social digital divide by the harmonised measurement of access and use of ICT in homes, based on a statistical indicator approved by the SocInfo program, whose objective is to obtain basic estimates on the levels and trends in the access and use of ICT with protagonism in the process of global *informationalisation*,[(1)] CEPAL (2010).

The Case Study

The MMA is located in the Mexican state of Nuevo Leon and formed by 12 municipalities: San Nicolás de los Garza, García and General Escobedo, Guadalupe, Juárez and Cadereyta Jiménez, Santiago, San Pedro Garza García, Santa Catarina, Apodaca and Salinas Victoria (see Figure 11.1 and 11.2). It inhabits 4.6 million people, equivalent to 4% of the total population of Mexico (N=127.5 million).

[(1)] The *informationalization* is the centrality of information as a process and product in society, (Castell, 1996).

Figure 11.1

Geographic location of MMA in relation to Mexican territory (source: SkyscraperCity, 2008).

Figure 11.2

Municipalities that integrate the MMA (source: Covarrubias, 2007).

Methods

Study Design

The methodological structure is organised into four evolutionary stages (see Illustration 1). The first is the categorisation of indicators of SDS measurement supported by the theoretical framework and the subsequent integration of a key indicator of access and use of ICT. The second refers to the construction of the database and its statistical exploration. The third weights and builds the Social Differentiation of Space Index (SDSI). The fourth considers the statistical analysis and the spatial visualisation of the SDSI and explores the relationship the index maintains with the indicator of access and use of ICT.

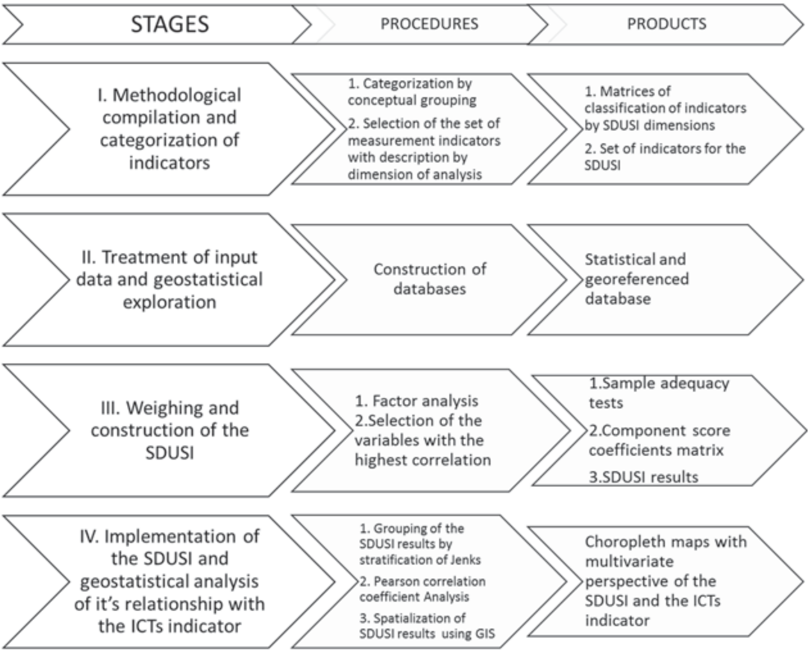

Figure 11.3

Scheme of the methodological stages, procedures and products.

Data Collection

The statistical information comes from the 2010 Population and Housing Census conducted by the National Institute of Statistics and Geography of Mexico. The space of analysis is composed by 1,661 AGEBs [(2)]. We excluded 195 AGEBs with gaps in the information. In 1,466 AGEBs corresponding to 87% of the MMA population seven socioeconomic indicators were estimated, including ICT access and use under the social rank construct. Finally, a georeferenced database of 7 columns (indicators) by 1,466 rows (AGEBs) was produced from which the SDSI was calculated.

Construction of the SDSI

The construction of the index requires a process of elaboration that consists of four phases and of the configuration of an algorithmic model that observes the independent variables of the phenomenon that leads to the reduction of data in the selected software: the statistical package for social sciences SPSS 24.0 of IBM (2016).

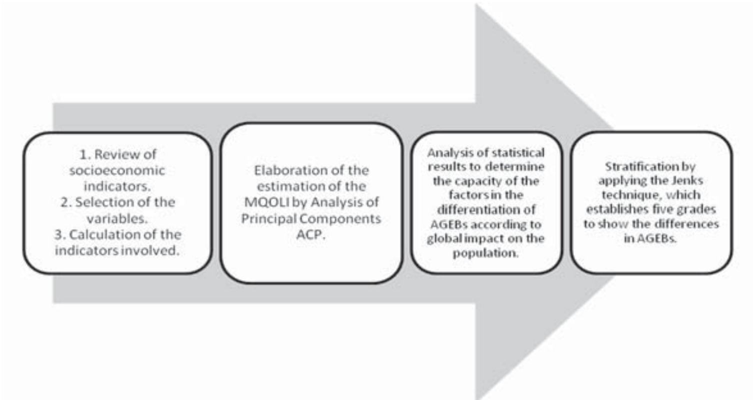

Figure 11.4

Elaboration process for the SDSI (source: own elaboration based on Conapo, 2010).

[(2)] Geo Statistical Basic Area (AGEB). It is the territorial extension that corresponds to the subdivision of the geo municipal statistics areas, (INEGI, 2010).

Geostatistical Analysis

The approach is quantitative and the test to check the feasibility of the factor analysis is the Kaiser-Meyer-Olkin (KMO) and Bartlett's Sphericity test (EB). The data is accepted only when KMO is greater than 0.5 and the level of significance of the Bartlett test are less than 0.1.

The method to be used is Principal Component Analysis (PCA). The PCA is a technique that extracts and prioritises information from large data sets and determines the number of underlying dimensions contained in a system of observed variables, known as "components," with the first component accounting for most of the variation in the data, Leva (2005). The VARIMAX Rotation was included for the ranking of significant variables and construction of a synthetic index of measurement.

Verification is sought through the sedimentation graph (scree plot) that graphs the size of the eigenvalues. The next is to validate the variables based on their communalities. Communality is the proportion of the total variation of a variable involved in the factors.

Finally, regression analysis is used with the intention of statistically verify if the variables have any relation between them. A double technique is used: the bivariate correlation and the scatter diagrams. The Pearson coefficient (r) value varies in the interval [-1,1], the sign indicates the sense of the relationship.

The classification method for grouping geographic data is the stratification of Jenks or natural breaks. Pearson coefficient (r) is applied to know the degree of correlation between the variables. In addition, Geographic Information Systems (GIS) are used to show the results of the statistical and spatial analyses, namely, to visualise the means in which territory is appropriated.

To show the geo-statistics information, we use a specific map type, the choropleth map of the Geographic Information Systems Software ArcGIS 10.4 for Desktop created by the company ESRI INC. Version 10.4.1.5686 (2015).

Results

Indicators Set for the SDSI

The set of indicators is presented with variables from the revised theory (Shevky and Bell, 1949 and Brindley and Raine, 1979), the measurement experiences found, (Schteingart, 2013; González y Villeneuve, 2007; Ariza y Solís, 2009) and the key indicators to assess the social conditions of access and use of ICT for Latin-American cities (CEPAL, 2010).The indicators were chosen because they present a greater possibility of measurement and because of the feasibility of obtaining them by level of geographical disaggregation see Table below.

INDICATORS OF THE SOCIAL DIFFERENTIATION OF URBAN SPACE INDEX						
sub-variable	construct	#	ID	+/-	indicator	calculation
Housing Income	Social Rank (occupation)	1	RS1_in_renta	+	rent_index	no. of dwellings with computer / Num. dwellings with the 4 products (computer, refrigerator, washing machine and TV)
Level of occupation		2	RS2_%_ocu	+	occupancy rate	number of employed / working-age population
Level of education		3	RS3_in_edu_sup	+	index_Edu_Sup	no. of persons older than 18 yo. with middle school education / num. persons over 18 years of age
Fertility	Urbanization (characteristics of the family)	4	U1_prom_hnv	+	average number of children born alive	given data
Single family accommodation		5	U2_viv_uni	+	total inhabited housing	inhabited private dwellings / total dwellings
Women's activity		6	U3_%_ocu_fem	+	female occupation rate	number of employed women / female population of working age
Isolation of ethnic groups	Segregation (ethnic differences in space)	7	S1_%_migra	+	average of people with migratory status	people born in another state / People born in the same state
		8	S2_%_indig	+	average population in households with ethnic status	population in indigenous census households / total state population

Table 11.2

Indicators of the SDSI in relation with the TSA.

For the SDSI the KMO test turned out to be 0.651, indicates that the adjustment of the sample, despite being mediocre, is acceptable for the implementation of the principal component analysis (see Table 11.3). The BE test was also considered, the SDSI obtained the value 0.000 of perfect significance ergo the null hypothesis (H0) can be rejected (that the variables under study are independent). In conclusion the factorial analysis of the ACP as appropriate.(3)

The sedimentation graph (see Figure 11.4) is used as a graphic contrast to know the number of components to be conserved,(4) shows the relevance of

(3) Bartlett's sphericity test checks whether the correlation matrix is an identity matrix, that is, that it has no significant correlation (p> 0.05) between variables (Conapo, 2010).
(4) Criterion called the arithmetic mean: the components with the steepest slopes are retained, CONAPO (2010).

using only the first three components of the index.

KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.651
Bartlett's Test of Sphericity	Approx. Chi-Square	8044.810
	df	28
	Sig.	.000

Table 11.3

Results of the KMO and EB tests of the SDSI by AGEB (source: own estimates based on the INEGI, Population and Housing Census, 2010).

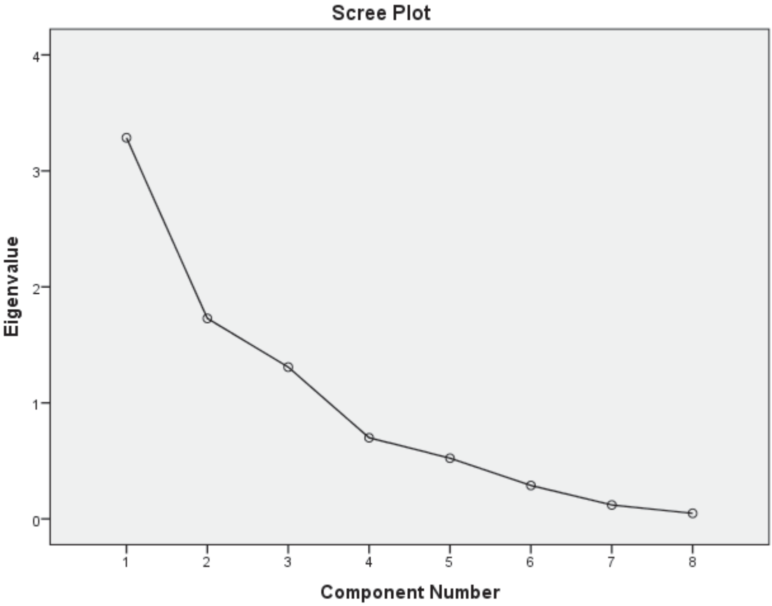

Figure 11.5

Sedimentation graph for the correlation matrix of the SDSI by AGEB. Source: Own estimates based on the INEGI, Population and Housing Census, 2010.

Component Score Coefficients Matrix

The ACP revealed that of the 7 indicators, 3 are the main components that explain 79% of the phenomenon: the percentage of private dwellings that have computers (RS1_in_comp), the percentage of people with a job (RS2_%_ocu), and average number of children born alive (U1_prom_hnv). The loads inherent to these indicators can be seen in the following table.

Rotated Component Matrix[a]

	Component		
	1	2	3
RS1_in_comp	.959		
RS2_%_ocu	.946	.151	
U1_prom_hnv	-.678	-.448	-.368
S2_%_indig	-.572		.551
RS3_in_edu_sup		.954	
U3_%_ocu_fem	.539	.722	
S1_%_migra	.131	-.305	.760
U2_viv_uni		-.326	-.716

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

a. Rotation converged in 6 iterations.

Table 11.4

Table of component loads. Variables of the SDSI at the AGEB level (source: own estimates based on the INEGI, Population and Housing Census, 2010).

Results of the SDSI

A stratification of Jenks [5] of five classes (very low, low, medium, high and very high) was chosen to determine the level of SDSI. The path of the index (-3.642880 a 4.916440).

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[5] In cartography, the Jenks classification method is used to divide the data due to natural breaks that occur in the data histogram at the low points of the valleys. The ruptures are assigned in relation to the order of the size of the valleys, with the largest valley being assigned the first natural rupture (Conapo, 2010).

Degree of social differentiation of space	Total		Limits of the interval	
	Number	Population	Inferior	Superior
Total	1 466	3 988 264		
Very low	225	595 987	-3.64288	-1.07002
Low	379	1 101 757	-1.070019	-0.32751
Medium	397	1 160 895	-0.327509	0.40667
High	267	685 985	0.406671	1.1843
Very high	224	429 140	1.184301	4.91644

Table 11.5

Stratification of the SDSI, by AGEBs and population (source: own estimates based on the INEGI, Population and Housing Census, 2010).

Mapping of the SDSI

On the left side of Map 3 the spatial distribution of the SDSI in the MMA is observed. A gradient of semaphore colours was used in negative, the red colour to represent a high degree of differentiation and in opposition the fluorescent green colour is used to mark the geographical areas with very low degree of spatial differentiation.

It is possible to observe the agglomeration of the maximum levels of social differentiation in a corridor that extends from the northwest to the southeast of the MMA, extending from the west to the southwest of the urban sprawl, showing a tendency of expansion from the south-southwest towards the south-southeast of the MMA. Corresponding to the municipalities of San Pedro, in the north of Santiago, to the western and southern region of Monterrey and, to a lesser extent, on the border with San Nicolas and Guadalupe, residential regions of high socioeconomic status.

The middle and upper middle classes are located in contiguity to the medium and very-high sectors respectively. This middle-class corridor is in a situation of contiguity to the left with very high levels (Monterrey and San Pedro) and to the right with very low levels of differentiation (Escobedo, San Nicolas and Guadalupe), serving as a buffer between the two extreme results of the index.

The low and very low socio-economic levels correspond to the areas with less spatial differentiation, located forming a peripheral crown that moves towards the northeast of the MMA, concentrating on the outskirts of Santa Catarina, Garcia, Escobedo and Guadalupe, suggesting a tendency to the expulsion of the central ring of the metropolis.

Figure 11.6

Comparison of the spatial distribution of the SDSI and number of dwellings with access to PC (source: own estimates with ArcGis 10.4 based on the INEGI, Population and Housing Census, 2010).

Regarding the first component, the Pearson R-value of 0.959 was positive so we can conclude that when the variable RS1_in_renta increases, the SDSI level also increases. The Sig (2-tailed) value is analysed, which indicates whether there is a statistically significant correlation between the two variables. In this case Sig=0.000 is less than or equal to .05, so we can conclude that there are statistically significant correlations between the two variables (see Table 11.6).

Correlations

		REGR factor score 1 for analysis 1	RS1_in_comp
REGR factor score 1 for analysis 1	Pearson Correlation	1	.959**
	Sig. (2-tailed)		.000
	N	1492	1492
RS1_in_comp	Pearson Correlation	.959**	1
	Sig. (2-tailed)	.000	
	N	1492	1537

**. Correlation is significant at the 0.01 level (2-tailed).

Table 11.6

Result of the bivariate correlation of the first main component RS1_in_renta and the SDSI (source: own estimates based on the INEGI, Population and Housing Census, 2010).

One can observe the spatial relationship between the SDSI and the access to a personal computer inside the house in the maximum and minimum ranges of the two variables. There is a decrease in the number of homes with access to a PC when approaching the peripheries of the MMA, coinciding with the low levels of SDS.

Negative Results

It is important to highlight that the variables of migratory condition did not appear among the main components that influence the SDS phenomenon, ranking 7 out of 7 variables studied and reporting a very-low positive correlation (r=.131).

Discussion

As stated in the introduction the available research report that the MMA presents the highest SDS in Mexico. These studies base their calculations on indexes that do not take into account indicators on access to and use of ICT. This exploration aimed to build a socio-demographical index that also takes into account the implications of the digital divide within the metropolis.

New Understanding of the Problem

Recalling the question that motivated this research is there a relationship between the digital divide and the geographical localisation of the spatial differentiation in urban space? It was found that in effect the main variable that explain the difference of SDSI levels by urban AGEB is the rent index that measures the number of dwellings with computer.

These results have a simple explanation, the variable that have to do with the access to a PC inside the household, is the one that resulted in the analysis of main components, and therefore the one that should be considered as a determining factor in the construction of the index. It is important to mention that the second component (see Map 4) of the phenomena was the occupancy rate (RS2_%_ocu) denoting the importance of access to the variables that specifically belong to the occupation dimension, as satisfiers of the construct social rank and key factors in the stratification of the social differentiation of space, for that reason the patterns of those variables in isolation are similar to those of the index.

Figure 11.7

Spatial distribution the occupancy rate (source: own estimates with ArcGis 10.4 based on the INEGI, Population and Housing Census, 2010).

In addition to answering the research question, what this work tried to prove is the hypothesis that this relationship supposes a positive correlation between the two studied phenomena: the greater the digital divide, the bigger the SDS. With the verification made in this study, it can be seen that in fact there is a strong relationship between the SDS phenomenon and the variable of access to and use of ICT (r=.959). The relationship between them is positive, meaning that to a greater digital divide, the bigger the SDS. Therefore, the alternative hypothesis (H1) is rejected and the null hypothesis (H0) is accepted, which implies a positive relationship between the SDSI and the variable of access to and use of ICT.

Conclusions

When making an analysis of the visualisation of the results we can observe a spatial distribution that confirms some of the ideas expressed at the beginning of this work, in the sense that it allows us to affirm that there is a complementary relationship between the digital divide, and the territorial fragmentation of the SDSI, that is to say that there is a marked digital inequality based on access to and use of ICT in the MMA.

By using the cartography and visualising the spatial distribution of the phenomenon, we can observe spatial coincidences of AGEB agglomeration with homogeneous scores. These agglomerations are not in territorial contiguity, but they form corresponding islands that can correspond to historic centres, commercial centres for the exchange of services, and to the political-administrative limits of the integrated municipalities in the metropolitan area. This can be related to the Model of the Latin American city: city of islands by Janoschka (2002) who states that Latin American metropolis move towards schemes characterised by fragmentation and whose urbanisation tendencies belong to a socio-historical situation product of post-colonisation and neo-liberalism.

Finally, it is concluded that the variables of the social rank, specifically those that refer to technological consumption, who represent the most evident aspects of the digital inequality in the SDSI of social groups and their distribution in space. Consequently, the digital divide in the MMA is shown as the space of conflicts where urban groups fight for a place to belong, clinging to the border that defines who stays outside and who stays inside or, as is the case of this research, among those who have access and ability to use ICT and those who do not.

Next Steps

Future research points to expand the experimentation and integrate different indicators of access to and use of ICT to observe the degree of influence the *informationalisation* processes have in the means social territory is appropriated.

References

1. Aparicio, Ortega & Sandoval. La segregación socio-espacial en Monterrey a lo largo de su proceso de urbanización. Región y sociedad, XXIII (52), 2011.
2. Ariza, M. & Solís, P. Dinámica socioeconómica y segregación espacial en tres áreas metropolitanas de México, 1990 y 2000. Estudios sociológicos xxvii, 79, 2009.
3. Arquette, T. Assessing the Digital Divide: Empirical analysis of a meta-analytic framework for assessing the current state of information and communication system development. Simposium de

la IAMCR y la ICAS sobre Brecha Digital, Texas, 2001.
4. Brindley, T. S. & Raine J. W. Social area analysis and planning research. Urban Studies. (16). pp. 273-289, 1979.
5. Castells, M. The rise of the network society. Blackwell Publishers, 1996.
6. CEPAL, Indicadores sobre acceso a y uso de TIC en Censos Seminario-Taller los censos y las condiciones de vida, Chile, 2010.
7. CONAPO. Metodología de estimación del índice de marginación urbana, México, 2010.
8. Contreras, C. Geografía de Nuevo León. Fondo Editorial de Nuevo León, 2017.
9. Covarrubias. A. Monterrey metropolitan area. Wikimedia Project, 2007.
10. DESAL. Marginalidad en América Latina. Herder, 1969.
11. Escobar, C. A. Pauta espaciales de la calidad material de vida: Una lectura urbanoscopica de la metropoli de Monterrey. Universidad Autónoma de Nuevo León: Facultad de Arquitectura, 2011
12. Gonzalez, S. & Villeneuve, P. "Transformaciones en el espacio socio residencial de Monterrey, 1990-2000". Estudios Demográficos y Urbanos XX (1): 143-178, 2007.
13. INEGI. Censo de Población y Vivienda. Principales Resultados por Localidad (ITER): Descripción de la base de datos. México, 2010.
14. Janoschka, Michael. El nuevo modelo de la ciudad latinoamericana: fragmentación y privatización. EURE, 28, 85, 2002,
15. Katz, Jorge & Hilbert, Martin. Los caminos hacia una sociedad de la información en América Latina y el Caribe. CEPAL, 2003.
16. Leva, Germán. Indicadores de Calidad de Vida Urbana: Teoría y Metodología. Universidad Nacional de Quilmes, 2005
17. Norris, P. Digital divide. Civil engagement, information poverty and the Internet world wide. Cambridge University Press, 2001
18. OECD. Understanding the digital divide. OECD, 2001.
19. Shevky, E. F. and Bell, W. Social Area Analysis: theory, illustrative application and computational procedures. Stanford, 1955.
20. Skyscrapercity. Monterrey incluyendo su zona metropolitana. Dragonbyte Technologies Ltd: México, 2008.
21. Schteingart, M. La division social del espacio en las ciudades, Perfiles latinoamericanos, (10)19, 13-32, 2001.
22. Schteingart, M. Desigualdades socio-espaciales y segregación en ciudades mexicanas, Seminario: las desigualdades y el progreso en México. COLMEX-INEGI, 2013.

I.3

SCAVA METHODOLOGIES IN BUILDINGS

CHAPTER TWELVE

THE *GALLERIA PROGRESSIVA* IN THE SOLOMON R. GUGGENHEIM MUSEUM AND THE MUSEUM OF UNLIMITED GROWTH

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MARIA JÚLIA JABORANDY

Introduction

This paper fits within a broader PhD research, currently in progress, on museum visitors' engagement within uninterrupted sequential spaces named *galleria progressive*,[(1)] utilising the social logic of space (or Space Syntax) and neuroscience as theoretical grounds. Using configurational analysis, two emblematic museum concepts will be specifically discussed here, the Solomon R. Guggenheim Museum (1943–59) by Frank Lloyd Wright, and the Museum of Unlimited Growth (1939) by Le Corbusier. These two cases are compared because they are examples of a thorough application of the *galleria progressiva* in modern architecture, where, although having distinct shapes, their spatial and formal conceptions are based on the logic of the spiral, as well as having the same use as museums.

With regard to previous studies,[(2)] especially in the Space Syntax field we intend to extend the discussion of some of these seminal ideas often related to criticising the *galleria progressiva* for its reductionism of route

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[(1)] Bennett[2] and Bann,[20] as well as the synthesis Sutton[5] performs on these two authors, have published relevant studies on museums that include discussions on the *galleria progressiva concept*.
[(2)] Hillier and Tzortzi[21] present a review of main studies on museums that, focusing on different aspects related to their spatial systems, are all based on the theory of Space Syntax.

possibilities[(3)] and restriction of spatial structure experience, which tends to leave, as in the Guggenheim, “no room for probabilistic effects of the layout over exploration and encounter.”[1] The following questions permeate the investigation: Which of the two spatial systems discussed here is more favourable to engagement? And which configurational particularities lead to the probability of engagement?

We begin by defining the *galleria progressiva* as a type of nineteenth-century museum organisation, then, contextualise the two museum concepts according to such type, setting the basis to the analysis. Following, we present and discuss the analysis of both case studies through convex, axial and visibility maps, isovists, and justified graphs to, then, reach some conclusions.

The *Galleria Progressiva*

Approaching the Galleria Progressiva

Toward the end of the nineteenth-century, museums went through a process of creating a new space at the same time rational and scientific, where specialisation and classification became distinguished features, leading, early in the century, to a historicised framework in exhibit displays. Bennett observes that this was an important innovation coinciding with the developments of various disciplines and practices wishing to reproduce the past and its representation as a sequence of phases towards the present.[2] Newhouse agrees, noting that public museums “imposed clear directions for movement through their galleries, presenting ‘walk-by’ viewing that after 1750 developed into chronological organisations emphasising history”.[3]

Based on pioneering initiatives in historicised principles of display in France, (Musée de Monuments Français [1793] and Alexandre du Sommerard’s collection at the Hôtel de Cluny), some scholars have suggested two main types of museum spaces at the time: the *galleria progressiva* and the period room. Although not the focus of this paper, the period room, according to Pevsner, was the organisation “principle of the

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(3) Choi[22] investigated how much the movement of visitors was determined by the spatial configuration, rather than objects on display, in eight American art museums. His findings led to two models of space regarding their role in structuring the pattern of movement: the deterministic model, which forces movement as choices are restricted, and the probabilistic model, which allows movement to be more random, but modulated by configurational variables.

future",[4] configuring an enfilade or rooms in line with each other. Regarding content, these rooms were organised chronologically by period, although, inside often relied on additional texts and labels to better direct visitors.[5]

To satisfy the historical demand of the nineteenth-century, art museums found that showcasing history in a progressive articulation was ideal to integrate its fragments, which suited the *galleria progressiva* and the ability of its geometry to guide visitors by ordering the artworks along its walls, setting visitors' paths freer of external clues than in the period-room format. Sutton suggests that this scheme can develop in any geometry allowing visitors the simple rule of following artifacts progressively, and can take various shapes, typically a helical structure, straight line or vaulted tunnel, concentric squares, concentric hexagons, concentric circles, or combinations of these.[5]

Galleria progressiva precedents include early straight-line galleries, such as the Antiquarium (G. Strada, 1569-71), the statuary gallery at Sabbioneta (V. Scamozzi, 1583–90) and the Louvre's Grande Galerie (1793). O'Doherty's refers to a very engaging space while commenting on an 1832 painting depicting the Louvre: "one can see the nineteenth-century audience strolling, peering up, sticking their faces in pictures and falling into interrogative groups a proper distance away, pointing with a cane, perambulating again, clocking off the exhibition picture by picture."[6]

Concentric variations of the *galleria progressiva* go back to the Vatican's Museo Pio-Climentino (1773) rotunda-shaped statuary room and Pièrre-Adrien's study for Musée des Beaux Arts (1810) with sixteen galleries arranged radially from a central rotunda. Other incipient projects were the museum-themed competition Prix de Rome by the Académie d'Architecture in Paris (1753 through to the early nineteenth century), including straight-line, vaulted tunnel galleries, and rotundas amongst the awarded designs. E.-L. Boulée's museum (1783) and Durand's Précis des leçons (1802–09) are also relevant examples combining a Greek cross over a square plan departing from a central rotunda.

The Glypothek (1815–30) and the Alte Pinakothek (1823–36) in Munich by Leo von Klenze, and the Altes Museum (K.F. Schinkel, 1823–30) in Berlin, also contained *galleria progressiva* spaces. The Glyptothek had sculpture galleries arranged chronologically in a continuous ring around an inner courtyard. The Altes Museum translated Durand's plan, with a large central rotunda flanked by two courtyards and closed at the sides by long galleries. Displaying paintings by schools, The Alte Pinakothek had service spaces and a library on the ground floor, and galleries upstairs, with the floor plan set in three parallel strips—two for paintings and one access loggia—along twenty-five bays, a scheme adopted several times later, notably in the Neue Pinakothek (August von Voit, 1846–52) in Munich, and in the Dresden Gallery (G. Semper, 1847–55)[7] (Figures 12.1–12.4).

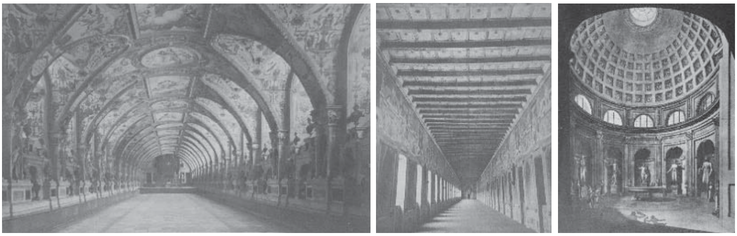

Figure 12.1

(a) Antiquarium (G. Strada, 1569–71), (b) Sabbioneta (V. Scamozzi, 1583–90) and (c) Museo Pio-Climentino (1773).

Figure 12.2

Exhibition Gallery at the Louvre, painting by Samuel F.B. Morse (1832–33).

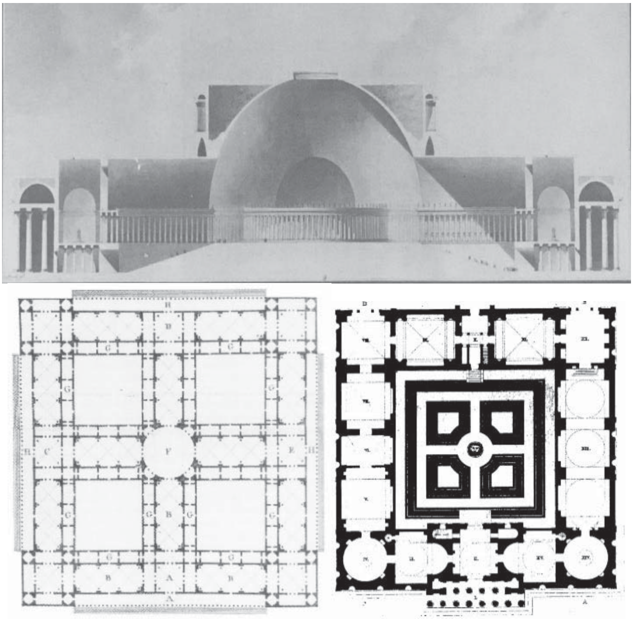

Figure 12.3

(a) Boulée's museum (1783), (b) Durand' Précis des leçons (1802–09) and (c) the Glypothek (1815–30).

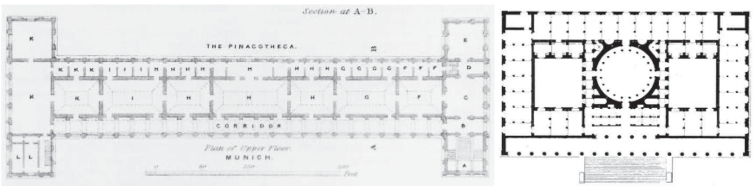

Figure 12.4

(a) Alte Pinakothek (1823–36) and (b) Altes Museum (1823–30).

The Solomon R. Guggenheim Museum (1943–59)

Sutton claims the Guggenheim's helical structure is the first example of a *galleria progressiva* fully applied to an art museum.[5] It was conceived by Frank Lloyd Wright to house Solomon R. Guggenheim's paintings, one of the first American collectors of abstract art. The design included four major schemes (A through D) and revisions to scheme A. After expressing his ideas in writing for a year, Wright's preliminary studies started in March 1944, when the building site was acquired. These schemes "were all based on the same parti […] One was hexagonal, the other three variations on a circle […] The key element was an approximately eight-story 'tower' occupying the right half of the site"[8] enveloping a spiral-shaped ramp occupied by galleries that developed around a rotunda crowned with a glass dome.

Scheme "A", client approved in July 1944, showed two main circular volumes—galleries and atrium at South, and the administrative tower at North—and a third, smaller cylinder with an elevator West of the gallery tower. Several revisions occurred afterwards, through which the elevator remained the most integral component. After Solomon Guggenheim's death in 1949 and the purchase of the remaining portion of the building site on 5th Avenue, the Guggenheim Foundation fired its influential former director, Hilla Rebay, hiring, in 1952, James Sweeney, previous Museum of Modern Art's curator. At the same period, the final layout was established, and, after a few more revisions, construction began in 1956. Wright died in 1959 prior to the museum's opening later that year[8] (Figures 12.5 and 12.6).

The museum's main form is a helical *galleria progressive*; although modified by adjacent galleries, added increasingly after 1992's major renovation,[9] it provides visitors with two main route options, up or down the spiralling ramps around the atrium—a deterministic rule on visitors' movement. In a harsh criticism, Pevsner notes that "Sensational it surely is, but it is also about everything a museum should not be. It is a monument, after all, and the spiral ramp which one is forced to descend makes any cross moves impossible, and cross moves at will are the spice of museum visits."[4] At the same time, the voided space of the atrium plays a key role in articulating the space, creating a difference experience than that generated by the ramp itself. Both observations are particularly relevant to our study once movement and the possible interactions that might occur in voided spaces are at the basis of Space Syntax theory.

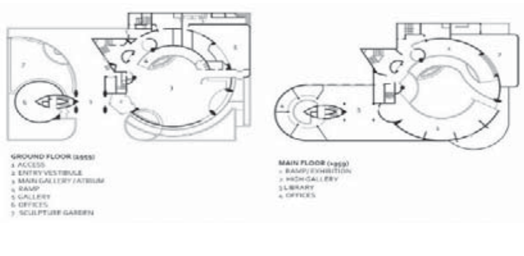

Figure 12.5

Ground and main floor plans of Solomon R. Guggenheim museum (1959).

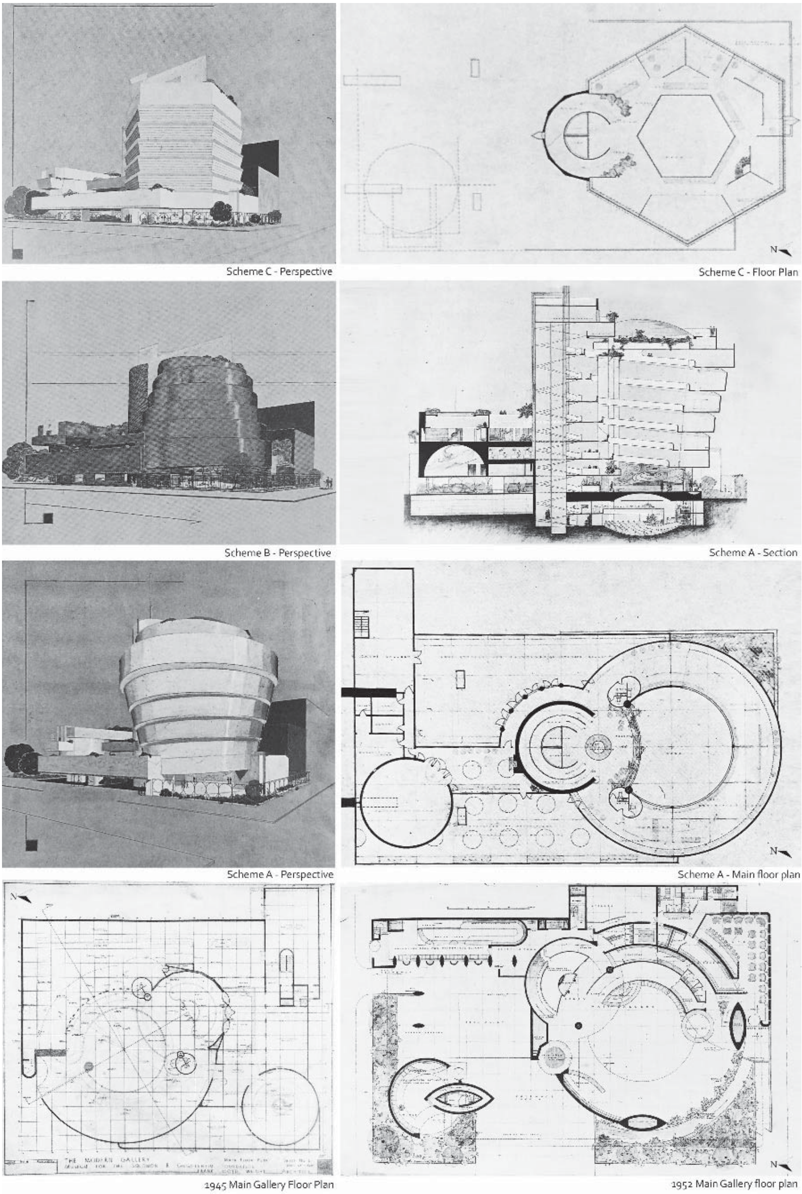

Figure 12.6

Solomon R. Guggenheim Museum schemes from 1944 through 1952.

Letters exchanged between Wright and the client reveal the architect's concept. On January 20, 1944 he wrote: "A museum should be one extended expansive well-proportioned floor space from bottom to top – a wheel chair going around and up and down, throughout. No stops anywhere and such screened divisions of space gloriously lit within from above".[10] Wright's interest in the movement of visitors, shared with Space Syntax's theoretical framework, is evident, emphasised by the presence of a wheelchair moving with ease in a spatial layout with partitions detached from ceilings, conforming a unified well-scaled space where exhibitions and building are linked continuously. One can notice the intention to link building and exhibitions, which relates to Sutton's definition of the *galleria progressiva* as a scheme where the visitor's route is led by the museum's geometry and the sequential display of artworks it imposes.[5]

In June 1958 Wright emphasised visitor's movement, circulation and artwork viewing: "Walls slant gently outward forming a giant spiral for a well-defined purpose: a new unity between beholder, painting and architecture. As planned, in the easy downward drift of the viewer on the giant spiral, pictures are not to be seen bolt-upright as though painted on the wall behind them. Gently inclined, faced slightly upward to the viewer and to the light in accord with the upward sweep of the spiral, the paintings themselves are emphasised in themselves and not hung 'square' but gracefully yield to movement as set up by these slightly curving massive-walls."[10] The museum's social space is illustrated in the activity and social gatherings (visitors moving continuously, subject to encounters) that a spatial layout can facilitate.

Wright's words suggest a balanced appreciation of architecture and artwork, although privileging the scale of the building in relation to the varying scales of exhibition spaces. This relationship also concerns Peponis who refers to three desirable spatial considerations in museums: linkage between exhibit spaces and the building as a whole via foyers and major circulation routes; balance between the appreciation of the architectural object and effective exhibitions; and the interface between building scale and the varying scales of the exhibits.[1]

Wright's control over the visiting experience shows in the minimisation of visual contact with the outside, and in the monitor, the smaller office tower. Even after the 1990's renovation, when offices became galleries and store, the previous vigilance of higher hierarchy staff at top floors over those working below by means of a central void, was replaced with that of security guards and staff over visitors on the ground level store, also attracting potential shoppers from upper galleries. This relates to the idea that a labelled space can reproduce specific types of social relations and power amongst users, as well as, to the notion that the project "operates against some background of legality and that this legality is itself rooted in the properties of form"[11] (Figure 12.7).

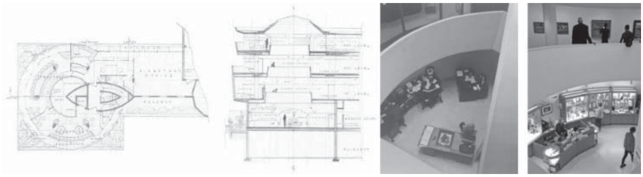

Figure 12.7

The monitor tower: (a) top floor plan and section (1943); (b) ground floor (1959) and (c) store and exhibition space (2016).

The Museum of Unlimited Growth (1939)

Moos states that one of the paradoxes in Corbusier's work is the relative independence that forms develop in relation to the specific purposes they serve, adding that 'barely more than three or four themes (or functions) led to definite architectural types: the dwelling module (box), the museum (spiral), the stadium (bowl), and to a certain degree the assembly hall (triangle).[12] The Museum of Unlimited Growth (MUG) exemplifies Moos' spiral type and the *galleria progressiva*. It is a conceptual scheme that fits within "a set of projects known as the spiral museums, which Le Corbusier and his studio worked on between 1929 and 1965. The 1939 museum comes after a decade of research by the architect into this "prototype", in which a square spiral form is used as a plan".[13] Three museum spirals were actually built (Tokyo, Ahmedabad, and Chandigarh), fourteen others conceptualised, but none focused specifically on the possibility of unlimited growth (Figure 12.8).

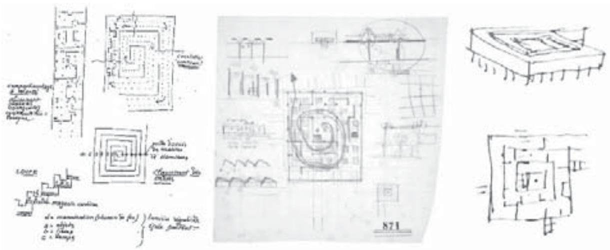

Figure 12.8

Spiral in Le Corbusier's projects: (a) The World Museum (1928–29); (b) Pavilion des Temps Nouveau (1936–37) and (c) Museum of Unlimited Growth (1939).

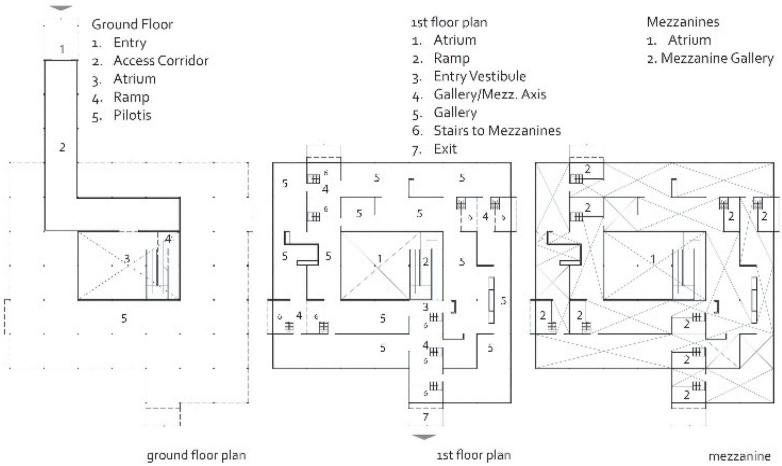

Figure 12.9

Museum of Unlimited Growth ground, main and mezzanine floor plans.

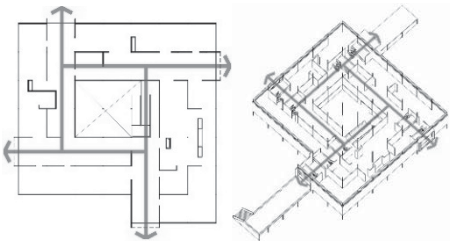

Figure 12.10

Diagram of main floor plan and isometric view showing four axes.

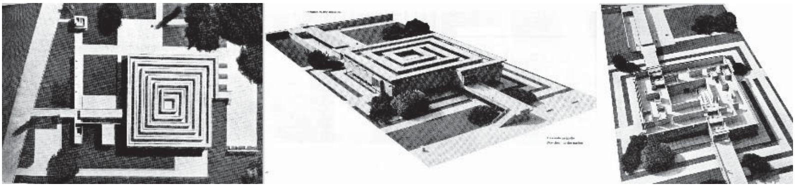

Figure 12.11

Views of physical model.

The floor plan is a result of the combination of the spiral and the swastika forms, which the architect had tried in prior spiral schemes. While the spiral form defines the main layout of galleries/corridors, the swastika takes the shape of four pinwheel axes overlaid on the spiral.[14] These two elements are enveloped by a quasi-cube standing on *pilotis* which is accessed from a ground floor entrance that directs visitors straight to its midpoint, an open atrium containing a ramp that leads to the main floor galleries (Figures 12.9–12.11).

Similar to Wright's helical ramp, the visitor's route is predetermined by the architect, although, as our analysis will show, the cross moves referred by Pevsner as impossible in the Guggenheim are made feasible in Corbusier's museum by means of openings towards the exterior (at each pinwheel axis) and through the perimeter walls of the spiralling galleries. Perhaps this was one of the reasons why Moos commented that, although Le Corbusier's museums "may be of modest architectural caliber",[12] they fulfil the purpose of a museum better than Wright's Guggenheim. Moulis seems to agree with this while suggesting that the insertion of the four axes by Corbusier brings a certain unity to the plan that attenuates the possible labyrinth effect of the main spiral circulation. Although a spiral circulation is not labyrinthine per se, as in this case, it has some spatial properties of a labyrinth, such as the visitor not being able to see the exit right away.

Consistent with this idea, Colomina writes that in the MUG the architect further increases "the possible trajectories",[15] adding that in his spiral museums "Le Corbusier emphasises the surprising lateral views within labyrinthine spaces".[15] Based on such remarks, the question of permeability within the interiors and towards the exterior, another common interest with the field of Space Syntax, seems to be crucial in understanding the two cases of *galleria progressiva* which this paper focuses on.

Just as in Space Syntax, movement is a key element in Le Corbusier's projects. Although scholars often focus on the graphical analogy between MUG's form and spiral forms in nature and mathematics, Moulis believes the spiral is used as a generating device as shown on the architect's drawings, involving altogether 20 projects, that address circulation patterns and plans through freehand lines testing paths of movement.[16] This is relevant as a recurrent theme in Le Corbusier's work is the architectural promenade, a concept referring to free exploration of an environment in a sequential mode based on the spectator's movement and point of view. But, could a labyrinthine layout offer free navigation? Moulis argues the mechanistic effect of the layout is somewhat pertinent to Le Corbusier's promenade concept since in his works he aimed to determine desired experiential effects, that are "a kind of figuration of experience",[16] of course, not all are related to the labyrinth configuration.

The Analysis

Means and Methods

We performed ground and main floor plans analysis of the Guggenheim's inaugural layout (1959) and Le Corbusier's MUG. For Wright's museum we used documentation[17] by the Guggenheim Foundation and renowned scholars.[(4)] As there is no final plan per se for Corbusier's project, we created our own backgrounds and 3D model based on sketches and physical models by the architect available at Foundation Le Corbusier[(5)] and in

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[(4)] Some of the most relevant works by scholars and the Guggenheim Foundation are Levine[8], Siry,[23] and The Guggenheim.[24]
[(5)] The digital archives are available at: http://fondationlecorbusier.fr/corbuweb/zcomp/pages/ArchM098.htm.

Ouvres Complètes 1938–46;[(6)] therefore, as we tried to be as accurate as possible to these sources, the graphics produced reflect our interpretation of the existing material. We used DepthmapX[(7)] and JASS software to generate, respectively, maps and justified graphs, as well as AutoCAD and SketchUp for producing floor plans and 3D models. Although not the focus of this paper, we also performed different types of field observations in the Solomon R. Guggenheim Museum.

The Use of Space Syntax in the Analysis

In space syntax's theoretical approach there is a key idea: people move in axial lines, interact in convex spaces, and see visual fields that change as they move through built environments.[18] Using graph theory to describe layout configurations makes it possible to investigate the correlation between space configuration and social behaviour.

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(6) *Le Corbusier Oeuvre Complète* (1938–1946) is a mandatory resource when studying Le Corbusier's work.

(7) Turner[25] is a very helpful resource regarding Space Syntax's latest developments through the use of DepthmapX.

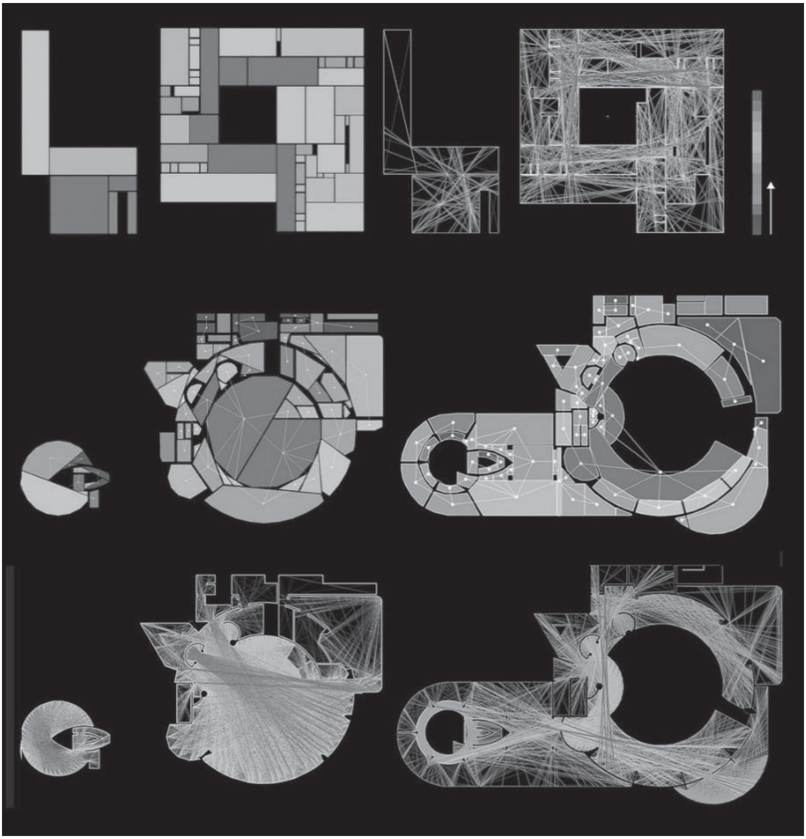

Figure 12.12

Convex and all-line maps of the Museum of Unlimited Growth (Le Corbusier, 1939) and the Solomon R. Guggenheim Museum (Frank Lloyd Right, 1943–59).

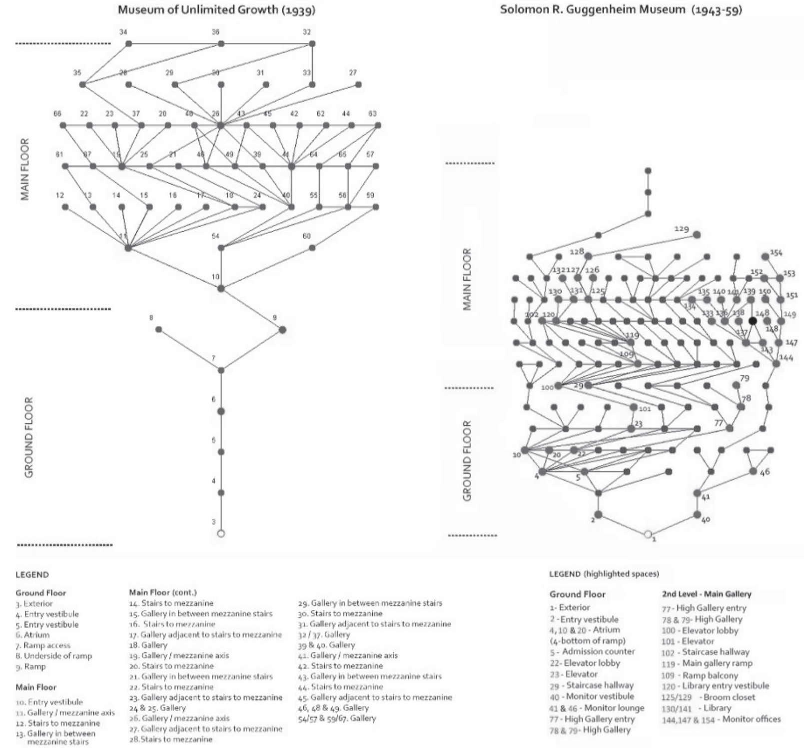

Figure 12.13

Justified graphs highlighting relevant spaces in red.

MUSEUM OF UNLIMITED GROWTH - Whole System

	A	B	C	D	A+B+C+D
	16	6	18	17	57
Totals	28,07%	10,53%	31,58%	29,82%	100%

GUGGENHEIM - Whole System

	A	B	C	D	A+B+C+D
	45	50	39	17	151
Totals	29,80%	33,11%	25,83%	11,26%	100%

MUSEUM OF UNLIMITED GROWTH - Galleries

	A	B	C	D	A+B+C+D
	15	2	17	17	51
Totals	29,41%	3,92%	33,33%	33,33%	100%

GUGGENHEIM- Galleries

	A	B	C	D	A+B+C+D
	6	3	13	2	24
Totals	25,00%	12,50%	54,17%	8,33%	100%

Figure 12.14

“A”, “B”, “C” and “D” types of spaces in both systems.

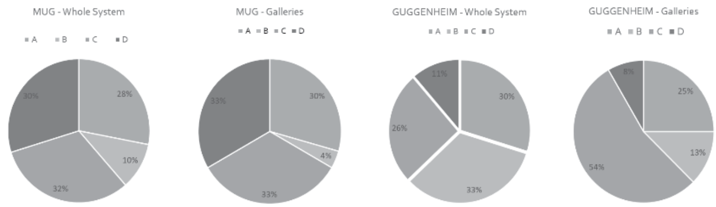

Figure 12.15

Charts of “A”, “B”, “C”, and “D” types of spaces in both systems.

Convex and axial maps were used to analyse connectivity, integration, and intelligibility, as well as a correlation coefficient between the two that, when high, indicates how easy it is for someone in a local position to understand the overall structure, helping to predict pedestrian movement.[(8)] Visibility graph analysis (VGA) was used to analyse visual properties of the layouts, especially integration (fewest number of connections that need to be traversed to reach one node from another).[(9)]

Justified graphs were used to analyse depth, branching trees, looping rings and relative asymmetry within the spatial systems. With the base node set in the exterior, the remaining points are horizontally aligned above it according to their respective depth. We have highlighted in red the most significant spaces referred to in our comments. In the Guggenheim’s graph we only numbered the spaces we think are most relevant within the system.

Discussion of the Results

While Wright’s museum is a built project that went through revisions due to demands from client and local building code, Corbusier’s is a conceptual museum. The Guggenheim’s program, even if considering only the two floors being tested here, is more complex than the latter, including galleries, offices, restrooms, library, and service spaces not accessed by the usual visitor. In contrast, in Le Corbusier’s layout almost all spaces are labelled as gallery and accessibility is less restricted, affecting the spatial

[(8)] Al-sayed *et al.*,[26] Dalton *et al.*,[27] Hillier and Hanson,[28] and Hillier *et al.*[29] are fundamental resources for understanding such concepts.

[9] Al-sayed *et al.*[26] is a very helpful, relatively easy to follow manual on Space Syntax that includes tutorials for performing various types of analysis via maps, as well, as pulling out data from such maps and analysing it.

relationships within the system.

Considering just the galleries, there are 51 convex spaces in the MUG, and 24 in the Guggenheim. Within the whole system, in Corbusier's project the number of convex spaces is 57, increasing to 151 in Wright's. On Guggenheim's main floor, one convex space represents almost 50% of all other exhibiting spaces in the rotunda's atrium. MUG's main floor galleries are more intricate, with larger convex spaces in the four axes and many others evolving within the spiral (Figure 12.12).

Hillier[41] differentiates four types of spaces per number of their connections to other spaces and if these are positioned within rings of movement: "A" are dead-end spaces; "B" is connected to two or more spaces but not within a ring; "C" is often in one ring; and "D" must be located in two or more rings. The number of "D" spaces is way higher in the MUG, but "A" spaces occur similarly in both cases. "C" spaces are more frequent in MUG, but the Guggenheim has more "B" spaces. Higher global increase in "D" spaces would minimise spatial depth and generate an integrated system, whereas global increase in "B" types and local increase in "C" types concur for a more segregated system (Figures 12.13–12.15).

In both systems spaces with higher connectivity are located in and around the atrium / rotunda. Most connected spaces at MUG are two of the galleries with mezzanines located in the axes (spaces no. 11 and 26), while in the Guggenheim these occur in the ground floor atrium and the ramp on main floor (Figures 12.12 and 12.13).

The ground floor atria in both projects are in a relative shallow position within their systems (depth 3,0), but when it comes to metric dimensions, the visitor travels a longer distance to reach MUG's atrium, perhaps indicating the architectural promenade's strength in Corbusier's scheme, although the architect deprived the visitor from any view of the exterior. The same happens with the most connected spaces at MUG, located in relatively deep positions within the system in comparison to Guggenheim's, which are situated in relatively shallow positions.

The 10% most integrated spaces are also located in and around the atria in both cases. At MUG, these spaces are indicative of alternative routes, including a gallery in one of the four axes (convex space no. 11), which is the most integrated within the system and contains the building exit. In the Guggenheim, the most integrated space is the elevator lobby, confirming the architect's emphasis on this component, where the museum visit was supposed to begin. It is also noteworthy that all highly integrated spaces in MUG are on the main floor, whereas in the Guggenheim they spread almost evenly on both floors. This mirrors Corbusier's layout, which places almost all exhibiting spaces on the same horizontal plane, while Wright's idea was the up and down viewing experience (Figure 12.17).

Correlating connectivity and integration, the Guggenheim spatial system is more intelligible than MUG's, which relates to the rotunda being the strongest element in Wright's conception, present in all schemes he designed for the museum. In Corbusier's project, although every turn around the atrium is marked by an axis facing the exterior, local visual cues relate less to the larger spatial structure than in the Guggenheim, but, on the other hand, there are more route alternatives (Figure 12.16).

	Museum of Unlimited Growth (1939)	Solomon R. Guggenheim Museum (1943-59)
Depth	12	17
Connectivity	2,45	2,37
Integration (Total RRA)	64,70	298,12
Integration (Mean Real Relative Assymetry	1,12	1,97
Inteligibility	-0,53	-0,36

Figure 12.16

General data for Museum of Unlimited Growth and Solomon R. Guggenheim Museum.

MUSEUM OF UNLIMITED GROWTH

		#	CONNECTIVITY	Integration	DEPTH
MF	ENTRY VESTIBULE	10	4	0,697	6
MF	GALLERY/MEZZ. AXIS	11	9	0,676	7
MF	GALLERY	18	4	0,749	8
MF	GALLERY	25	2	0,836	9
MF	GALLERY/MEZZ. AXIS	26	9	0,847	10
MF	GALLERY	40	5	0,769	8
MF	GALLERY	54	4	0,707	7

MF = MAIN FLOOR
GF = GROUND FLOOR

SOLOMON R. GUGGENHEIM

		#	CONNECTIVITY	Integration	DEPTH
GF	ROTUNDA/ATRIUM GALLERY	20	7	1,438	4
GF	ROTUNDA/ATRIUM	7	4	1,435	4
MF	MAIN GALLERY RAMP	119	7	1,432	9
MF	BOTTOM OF RAMP/GALLERY	76	2	1,425	4
MF	CIRCULATION	84	4	1,417	8
GF	ROTUNDA/ATRIUM	3	5	1,407	2
MF	STAIRCASE HALLWAY	106	2	1,403	8
GF	ROTUNDA/ATRIUM/GALLERY	10	9	1,394	4
GF	BTHRM HALLWAY	25	3	1,387	5
GF	ELEVATOR LOBBY	24	2	1,374	4
MF	CIRCULATION	98	3	1,345	8
MF	RAMP BALCONY	109	4	1,339	8
MF	ELEVATOR	101	2	1,275	6
GF	ROTUNDA/ATRIUM/ACESS TO RAMP/GALLERY	4	8	1,271	3
GF	ELEVATOR	23	2	1,270	5
	ELEVATOR LOBBY	100	6	1,248	7
GF	ELEVATOR LOBBY	22	4	1,247	4

Figure 12.17

10% most integrated spaces in Museum of Unlimited Growth and Solomon R. Guggenheim museum.

MUG's VGA graph shows several locations with drastic visual field variations, which concur for a richer experience. These spaces are located mostly at the four axes overlaid on the spiral. Isovists in these spaces illustrate extended visual fields. In the Guggenheim's main spaces visual fields do not change dramatically and the isovists, predominantly convex, have a high clustering coefficient (visual information lost when someone moves from one location to another), making it easier for interpersonal encounters or co-presence to take place in such spaces (Figure 12.18).

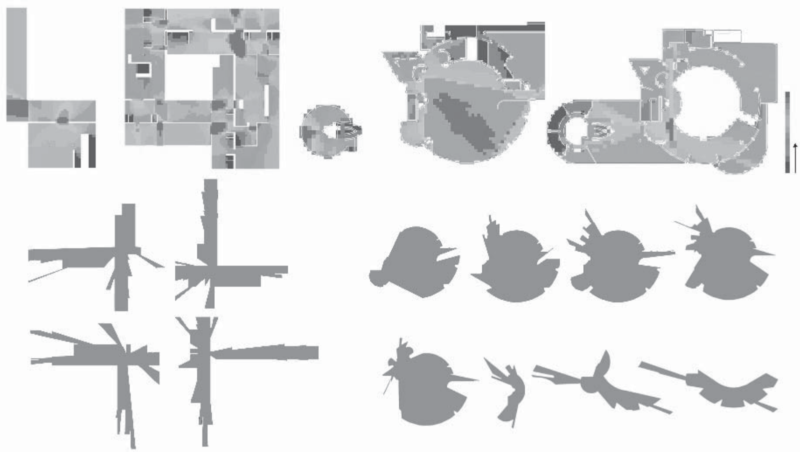

Figure 12.18

VGA graphs and isovists in high visual integration spaces in the Museum of Unlimited Growth and the Solomon R. Guggenheim Museum.

Conclusions

Overall, the MUG is a complex spatial system when it comes to convex partition, as galleries contain more components than the Guggenheim. The exhibiting spaces in the MUG vary significantly in size and shape compared to Wright's main spiralling galleries, offering visitors different experiences, independently from which works of art would be displayed.

Due to its many internal rings, MUG's system offers more crossline trajectories than the Guggenheim's restrictive up or down routes. At MUG, visitors may either follow the spiral's logic or detach from it through permeable connections in between galleries. We wonder if walking freely, visitors might even notice that the floor plan departs from a spiral. Perhaps

Corbusier's recurrent use of the architectural promenade and his awareness of a possible labyrinthine effect lead to this less deterministic condition. In the Guggenheim's inaugural layout, although there were few extra routes off the spiral, the main galleries were all in the rotunda, offering little chance for casual exploration of the space. Le Corbusier's spiral overlaid with four axes defines the configuration per se, while in Wright's layout, there is a hybrid of spiral galleries and adjacent spaces (elevator, High Gallery and monitor tower).

MUG's exit is made via a transversal segment in line with the access and populated with small mezzanines. At each turn around the central point of the system, the visitor might cross this escape route and the remaining 3 axes of the swastika, a strategy to allow the eventually bored visitor to either look outside or exit the building, suggesting that, while the spiral is used for its efficiency in adapting to the structure's future growth, it needed to be altered to avoid compromising a more exploratory experience. Therefore, more than Wright, Corbusier breaks away from the spiral and helps visitors find themselves in the endless spiral, either by showing them the exterior or letting them know they are about to initiate another turn in the spiral.

Going back to our initial questions, although testing visitor's engagement is part of an upcoming research phase involving simulations in virtual reality environments, we begin to collect initial clues on which system would be more favourable to engagement. Considering engaging as a condition tending to draw favourable attention or interest, and the idea that "Museums are safe and informal learning platforms, uniquely equipped to encourage visitors to imagine, explore, and experience",[19] Le Corbusier's concept for the MUG seems to be more favourable to engagement than Wright's Guggenheim because it allows visitors to have a more exploratory visit by maximising both route options and changes in visual fields during a visit.

References

1. John Peponis. 'Evaluation and formulation in design: the implications of morphological theories of function'. In Nordisk Arkitekturforskinning Nordic Journal of Architectural Research (2), 1993, p. 59
2. T Bennett. The birth of the museum: history, theory, politics. New York: Routledge, 1995. pp. 278.
3. V. Newhouse, Art and the power of placement. New York: The Monacelli Press, 2005. pp.302.

4. N. Pevsner, A history of building types. Princeton: Princeton University Press, 1976. pp.352.
5. T Sutton, The classification of visual art: a philosophical myth and its history. New York: Cambridge University Press, 2000. pp.184
6. B. O'Deherty, Inside the white cube: the ideology of the gallery space. Berkeley: University of California Press, 1999, pp.113.
7. T. Markus, Buildings and power: freedom and control in the origin of modern building types. London: Routledge, 1993. pp. 343.
8. N. Levine, The architecture of Frank Lloyd Wright. Princeton: Princeton Architectural Press, 1998. pp. 524
9. A. Rolim and L. Amorim, 'From Wright to Gwathmey Siegel: The case of movement in the Guggenheim museum'. In: Heitor, Tereza et al (eds), Proceedings of the 11th International Space Syntax Symposium, Lisboa: Instituto Superior Técnico, 2017. pp. 19.1 - 16.15.
10. B. Pfeiffer, Frank Lloyd Wright: the Guggenheim correspondence. Carbondale: Southern Illinois University Press, 1986, pp. 308.
11. T. Markus, and D. Cameron, The words between the spaces: buildings and languages. London: Routledge, 2002. pp. 196.
12. S. Moos, von. Le Corbusier, elements of a synthesis. Cambridge: MIT Press, 1988, pp. 379.
13. A. Moulis, 'Le Corbusier's spiral: figural planning and technique in architectural design'. In: Frascari M. et al. (ed.), From models to drawings: imagination and representation in architecture, New York: Routledge, 2007. p. 120-126.
14. A. Moulis, 'Le Corbusier's horizon: technique and the architectural plan'. In Architectural Theory Review, Vol. 8, Iss. 2, 2003. pp. 134-142.
15. B. Colomina, The Endless museum: Le Corbusier and Mies van der Rohe. In Log. observations on architecture and the contemporary city, New York, n. 15, Winter 2009, p.55-68.
16. A. Moulis, 'Le Corbusier, the museum projects and the spiral figured plan'. In: Takhar, Jaspreet (ed.) Celebrating Chandigarh Ahmedabad. Ahmedabad: Mapin, 2002. pp. 355
17. Richard Weston, As mais importantes edificações do século XX: plantas, cortes e elevações, Porto Alegre: Bookman, 2011. pp. 256.
18. B. Hillier and L. Vaughan, 'The city as one thing'. In Progress in Planning, Vol. 67 (3), 2007, p. 205-230.
19. E.M. Gokcigdem, Fostering empathy through museums. Lanham: Rownan & Littlefield, 2016, pp. 306.

20. S. Bann, The clothing of clio: A study in the representation of history in Nineteenth century Britain and France. Cambridge: Cambridge University Press, 1984. pp. 210.
21. B. Hillier and K. Tzortzi 'Space syntax: the language of museum space'. In: Macdonald, S. (ed.), A Companion to Museum Studies, Oxford: Wiley-Blackwell, 2011. pp. 282-301.
22. Y. K. Choi, 'The morphology of exploration and encounter in museum layouts'. In: Major, M.D. and Amorim, L. and Dufaux, D. (eds), Proceedings of the First International Space Syntax Symposium, London: University College London, 1997. pp. 16.1 - 16.10.
23. J.M. Siry, 2009. 'Wright's Guggenheim Museum and Later Modernist Architecture'. In: SOLOMON R. Guggenheim Museum, The Guggenheim Frank Lloyd Wright and the Making of the Modern Museum, New York: Guggenheim Museum Publications, 38-69.
24. The Guggenheim: Frank Lloyd Wright and the Making of the Modern Museum. R. Solomon Guggenheim Foundation, New York: Guggenheim Museum Publications, 2009. pp. 228.
25. A. Turner 'New Developments is Space Syntax Software'. In TURNER, A. (ed.), Proceedings of Workshop on New Developments In Space Syntax Software, Istanbul: ITU Faculty of Architecture, 2007. pp. 1-51
26. K. Al-Sayed, A. Turner et al. Space Syntax Methodology, London: Bartlett School of Architecture, UCL, 2014. pp. 117.
27. C. R. Dalton, H. Spiers et al., 'Navigating complex buildings: cognition, neuroscience and architectural design'. In: Gero, J. (ed.), Studying visual and spatial reasoning for design creativity, Rotterdam: Springer Netherlands, 2015. pp. 3-22.
28. B. Hillier and J. Hanson, The Social Logic of Space, Cambridge: Cambridge University Press, 1984. pp. 281.

CHAPTER THIRTEEN

PARTITIONING INDOOR SPACE USING VISIBILITY GRAPHS: INVESTIGATING USER BEHAVIOUR IN OFFICE SPACES

PETROS KOUTSOLAMPROS, KERSTIN SAILER, TASOS VAROUDIS

Introduction

Evidence-based design is the practice of observing and recording human behaviour in order to strategically inform design decisions. Studies show that this practice is becoming more and more popular in the field of architecture. Some studies claim that up to 80% of their respondents identified the need to capture the effects of their designs[5] while others that architects wanted to know more about new tools that enable them to inform their designs.[13] This interest has been especially prevalent in the design of workspaces. Seeking to reduce space (and thus cost) and increase productivity, companies have started looking into ways of collecting information about human behaviour in their workplace and using that information to re-design or optimise the office configuration.

In the search for patterns in human behaviour as they relate to the spatial configuration of office spaces various metrics have been developed. Initially the developed metrics were simple, such as the proximity between workers[1] and the existence of barriers,[7] but eventually more complex ones appeared, such as zone and path overlap.[10, 11] These metrics have shown promise in some cases but they have only been examined in a handful of spaces, tend to be unique to each study and do not thus reveal generic patterns that are true for any workspace.[15] The field of Space Synta0x has examined more complex methodologies, but those too have mainly been tested across small samples[8]. In cases where the methods were tested in larger samples the results tended to be inconclusive, or work with different subsets of cases.[12, 16] Therefore, the absence of generic patterns can not only be attributed to a lack of data, but also to the way of the methods themselves were constructed.

One of the problematic areas in the existing methodologies is the representation chosen to allow for the comparison of human activity to the configuration of the space. A few have been proposed, especially within the field of Space Syntax but they vary in how much detail they capture and how well they are suited for the appearance of human behaviour which occurs in distinct locations. The classic Space-Syntax representation of longest lines of sight[9] (axial-lines) focuses on movement rather than occupancy of space and is very abstract thus providing very little of the geometric intricacies of space. Convex spaces on the other hand provide slightly more detail and focus on occupancy, but they cannot be re-created reliably.[14] The representation suggested by Turner *et al*.[18] known as Visibility Graph Analysis (VGA) captures much more detail but, because it is based on a lattice grid, it is inflexible when trying to identify larger patterns of human behaviour.

In this paper, we suggest a spatial representation based on VGA that retains the amount of detail captured but also allows us to examine these larger patterns. We construct this representation by grouping continuous parts of the lattice grid into larger areas using the existing VGA metrics. These areas serve as the main unit of analysis and allow for a compromise between the amount of geometric detail captured and flexibility when capturing human behaviour.

We evaluate the results on a large dataset that contains information about human behaviour and configuration of office spaces. Our aim is to reliably identify whether areas that have the same properties attract the same behaviour: for example, whether areas more central to the building configuration attract more interaction or movement. We test across the dataset for generic patterns, but we also examine each case separately with the aim of understanding whether this methodology can be used to predict activity for any single given site.

The next section will review the existing methods and representations and provide details on their strengths and weaknesses. It will be followed by two sections describing the dataset used for the evaluation, and the suggested representation and methodology in detail. We will explain how this representation is generated as well as which aspects of it are variable and can thus be tuned to better approach the problem at hand. The final three sections describe the statistical testing framework used and its outcome, discuss the results and their general implications in the field of spatial analysis in the workplace and lay down future plans for the research team.

Literature Review

Human activity in space may be recorded in many ways, through sensors[4], video[2] or participant observations[20]. In all these cases, the output captured is expressed spatially as points or traces on a plan, depending on the method. In order to compare this output to the configuration of a space, a common framework is needed that allows both the human activity and the properties of the space to be quantified using the same general unit of analysis. Office spaces are very complex with many more spatial parameters affecting human activity than the ones examined in early research,[1, 7] highlighting the need for a more general framework, a reliable and fine-grained representation of indoor space. Within the field of Space Syntax three such representations have been proposed, axial lines, convex spaces and visibility graphs.

Axial lines were suggested by Hillier and Hanson in The Social Logic of Space[9] as the longest lines of sight that go through every space. These lines may be generated through an all-line analysis of the space, which connects the vertices of the walls of the plan between them and eliminates all but the minimum required to reach every space in the building. Given their one-dimensional nature they can very reliably represent linear spaces, such as corridors, as a single unit, but cannot unambiguously represent square-like spaces such as the large open-plan rooms found in office spaces. Axial lines were also made to represent movement rather than occupancy, thus although they can be used for indoor spaces, they are more suitable for urban scales for example to represent streets.

Hillier and Hanson identified that limitation and suggested a complimentary approach, what they called “convex spaces”. These are “the fewest and largest possible convex spaces” that can be carved out of a space. The process of constructing such spaces has been shown not be repeatable reliably by Peponis *et al.*[14] who examined the various existing approaches and highlighted the ambiguity in the process, evident in the example seen in Figure 13.1.

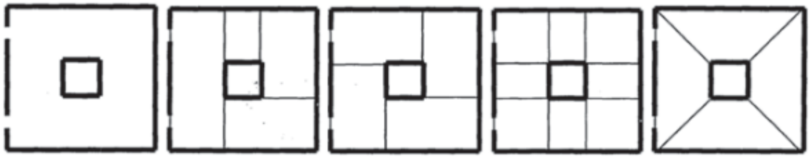

Figure 13.1

Sample plan and its possible minimum partitions by Peponis *et al*.[14]

While the lack of detail in both these representations can be thought of as a weakness, it may also be seen as a strength. The fact that they abstract so much of the geometric detail allows them to act as general units of analysis. In the case of axial-lines, one may compare the properties of a line (connections to other lines, depth) to the number of people found in its proximity. Convex spaces are also useful in that regard because they allow for comparing the properties of these spaces to the number of people within them.

Visibility graph analysis was developed as an alternative by Turner[18]. This method suggested splitting a space using a lattice grid and connecting the cells if they are inter-visible (through isovists as described by Benedict[3]), forming thus a dense graph. The underlying lattice grid provides a uniform unit of analysis (a cell) which also allows for a more detailed representation of the spatial configuration. It also creates a requirement to choose between the amount of detail and its ability to act as a general unit of analysis. If the lattice grid is created with small cells, then it can capture more of the geometric detail of the space, but the distinct locations of human behaviour will be distributed to a small number of cells that are in close proximity. This can be seen at the left in Figure 13.2 where the observations of people moving (blue dots) can only be assigned to the cell that is closest to their centre leaving the adjacent ones (pink) empty, although in terms of spatial configuration they are likely very similar to the red ones. If a large cell size is used, then more observations of human behaviour can be attributed to the same cell, but not as much detail can be captured. A large cell size also prevents the representation from capturing continuous space effectively. If for example the cells are larger than the door openings then the space on either side of the door will be inferred to be two distinct spaces as seen on the right in Figure 13.2.

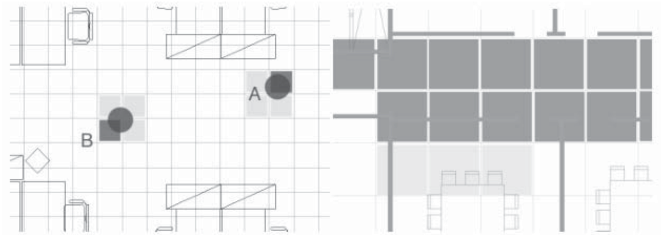

Figure 13.2

VGA Cell size issues. Left: Observations of people moving (blue dots), stepping on specific squares in the VGA lattice grid (red), while adjacent ones (pink), with similar values are ignored (cell size=0.45m). Right: If the cell size is large enough (1.5m) then the corridor and the meeting rooms are viewed as different spaces

In previously published research, we utilised VGA to identify patterns of human behaviour in the sample of office spaces also used in this study. We initially tried "smoothing" the human activity across the lattice grid using a gaussian kernel function.[12] This allowed cumulative effects to appear (see Figure 13.3), i.e., all cells were affected by the observations of human activity but the effect was greater for the cells closer to that activity. In a second study,[16] we examined the effect of human activity without this smoothing, by matching activity to the lattice grid cells directly, as seen in Figure 13.4. In both these cases the statistical tests returned insignificant results, stemming from confounding factors, but also by the lack of a proper method to generalise the presence of human behaviour.

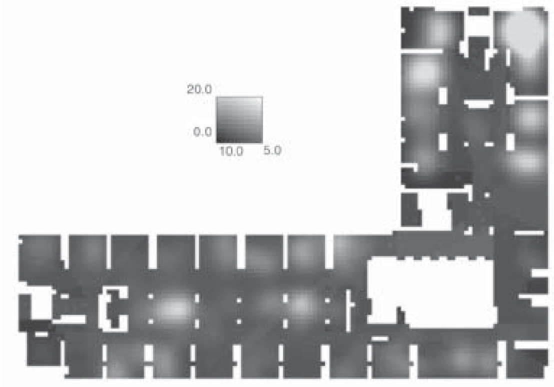

Figure 13.3

Visual Mean Depth Interaction density from Koutsolampros *et al*.[12]

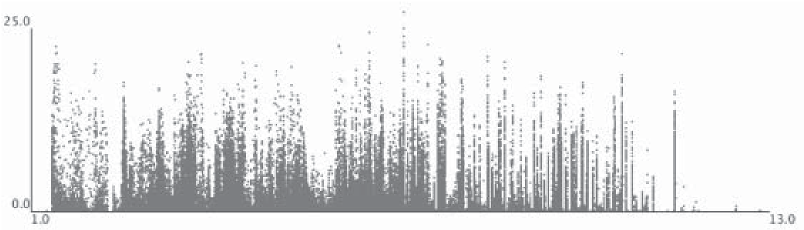

Figure 13.4

Visual Mean Depth (x-axis) and Interaction density (y-axis) for 27 case studies combined from Sailer *et al.*[16].

The small-scale decisions that happen during the design process specifically require practical spatial units that can also allow for meaningful generalisations of human behaviour. The above-mentioned lattice grid provides units that are too small, making any insights impractical when a designer is planning for whole rooms such as meeting rooms, kitchens, or workspaces, that contain many more cells. Hillier and Grajewski[8] used larger units (whole floors and buildings) in a study about configuration and human behaviour for offices in the UK, Scandinavia, and the USA, thus their results would only be useful in larger strategic decisions but not in the case of the many small companies that typically occupy a few rooms or floors within a building.

Data

To evaluate our representation, we examine an office-space dataset provided by Spacelab, an architectural office and consultancy in London, UK. The sample contains 34 different cases (sites), from 29 companies across the UK, compiled from 2012 to 2017. The companies examined vary in size (50 to 2700 desks) and come from different industries, such as Media, Advertising, Technology, Legal, and Finance.

There are two types of data for each case: observation data collected by participant observation[20] and visibility graph analysis. The observation data is collected usually over a period of five days, every one hour for eight hours, and it contains information of where people sit, stand, walk, and interact as points on a plan. Visibility graph analysis has been carried out with various versions of Depthmap[17] and depthmapX[19] that were available when each case was collected. For every site we examined two VGA metrics: Connectivity and Visual Mean Depth.

Methodology

Given that we consider the existing general units of analysis inadequate to capture both enough detail of the spatial configuration and sufficiently generalise human behaviour, we developed a solution that lies between the existing representations. Relying on the existing metrics of the VGA we group the various cells into different continuous areas, creating partitions of space similar to the convex-space representation. With this new representation we may now aggregate the observations of activity by the number of times it occurs within that specific group of cells, instead of matching each activity to a specific cell. This alleviates the problem of the activities happening in discrete cells and allows for general units of analysis comparison (areas) that more accurately describe the space than axial lines or convex spaces.

The process for generating these areas follows four steps:

- Construct a visibility graph and select a metric, e.g., Connectivity;
- Split the distribution of the metric into two parts according to a specific rule, e.g., by the median (this creates areas of high and low of the specific metric);
- Run a modified blob-detection algorithm that assigns areas to the cells depending on whether their adjacent cells belong to the same part of the distribution (low/high);
- Merge areas that are linked but are on different floors.

We initially tested the first three steps of this process across a small sample of simple-shaped plans with the results visible in Figure 13.5 below. For each of the simple plans (first row) the connectivity of the various spaces is calculated (second row) and split according to the median (third row). The modified blob-detection algorithm is executed with the split pixels as input, resulting in the different areas seen in the last row.

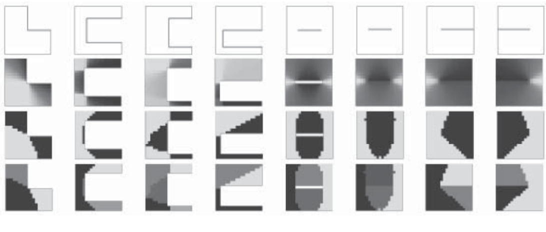

Figure 13.5

Per row: Plans, Connectivity metric, split by median and final areas.

We examined two visibility-graph metrics, Connectivity and Visual Mean Depth as well as their combination. Connectivity of a cell is the number of visible cells from that cell, and it can be thought of as a proxy for the size of visible space at each point. Visual Mean Depth on the other hand is the average number of turns required to reach every other cell in the building.

We also combined Connectivity and Visual Mean Depth into a single representation to achieve a more nuanced separation of spaces. Connectivity alone does not allow us to differentiate open-plan spaces from a long corridor and Visual Mean Depth focuses mostly on their centrality. With this combination we can identify those spaces as different types independently of office characteristics.

The cells are grouped by splitting the distribution of each metric and assigning the grouping to each cell. This creates semantically continuous spaces, such as areas with high or low visibility (high/low connectivity) or areas that are deep or shallow (high/low Visual Mean Depth). We split the distribution in various ways to test whether these splits affect the generation of the areas: by the mid-range, the mean and the median. The distribution for the two metrics for all cases can be seen in Figure 13.6 with the three splitting points.

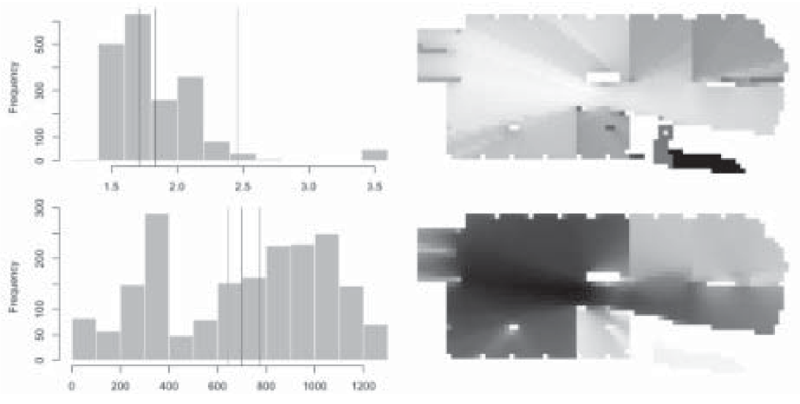

Figure 13.6

Distribution histograms (left) and values on plan (right, darker is higher) for Visual Mean Depth (top) and Connectivity (bottom). The different splits are shown in the histograms, green for Mid-Range, red for Median and blue for Mean.

The distribution of Visual Mean Depth tends to be heavily skewed to the left and thus a mid-range split tends to create areas that are uneven in size, with the very high values in one group and the rest in another as seen in the first row of Figure 13.7. The median provides a better split with half the values on the high area and half in the low, which in effect creates many more groups of similar value (Figure 13.7, second row). We also tested the mean of the distribution as a compromise between the two (7, last row).

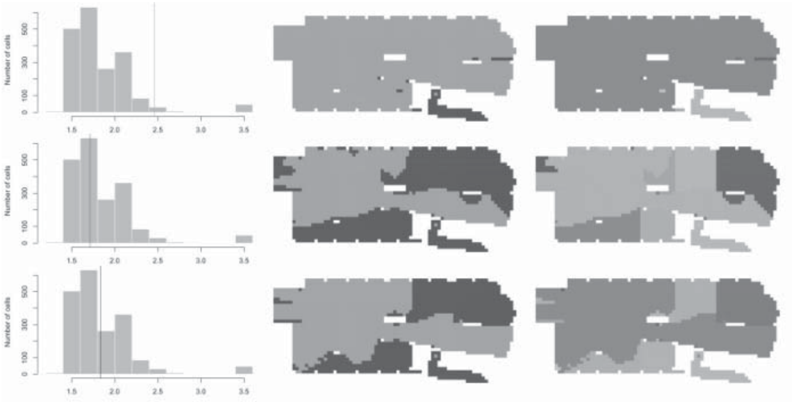

Figure 13.7

Visual Mean Depth histogram (left column), splits (middle column) and final areas (right column) for the three splits: Mid-Range (top row), Median (middle row), and Mean (bottom row).

The final stage of the process is an algorithm commonly used for blob-detection as described by A. Greensted.[6] In the typical use case, it is employed as a computer-vision algorithm to identify and detect "blobs": areas of similar colour in images. Figure 13.8 shows a part of the process. Through this process the cells of a lattice grid are classified according to the colours of their adjacent neighbours. In our method the types that were generated from the above-mentioned split (high/low Connectivity, VMD) are used as the colours of cells. Thus, if the neighbours of a cell are found to be of low connectivity, then that cell is classified with low connectivity as well.

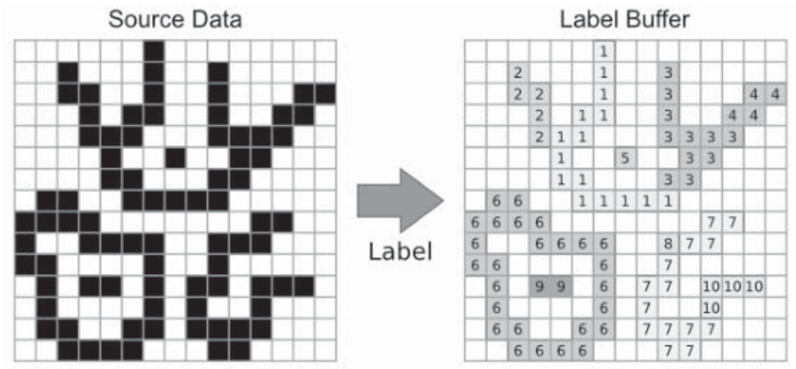

Figure 13.8

A part of the process of detecting “blobs”: continuous areas of the same type by Greensted[6].

Various alterations have been introduced to this algorithm for it to work in this specific domain. In contrast to the typical use-case our lattice grid is not completely filled as in the case of a camera image, thus, the exterior space is considered a type in itself. Also, in contrast to the typical use-case is the nature of the adjacency of the cell. While in blob-detection two cells are adjacent if there’s no gap between them, in our case the true adjacencies are provided by the visibility graph. While the centres of two cells can be at a distance of one cell (i.e., the cells have no gap between them) it is possible they are not actually inter-visible. In cases where the cells are larger than the widths of the walls it is very likely that two adjacent cells will end up in the same split but with a wall between them. In this case the blob-detection algorithm will assign them to two different areas given that perceptually these are actually different spaces. The last alteration of the algorithm is to allow it to merge areas that are linked between floors, if they belong in the same split group, are thus considered part of the same continuous space.

The examined output metric is the density of people observed within a specific area over one hour. We examine two types of activities, movement and interaction. We define movement as the number of people observed moving or standing during that hour, and interaction as the number of people seen interacting. Given that the size of the areas differs we calculate the density by dividing the numbers of people carrying out each activity with the size of that area in m^2. We also divide by the total number of rounds of each observation; therefore, the units of the density are people per m^2 and round.

Statistical Results

We tested against nine scenarios: all the possible combinations between the three metrics (Connectivity, Visual Mean Depth and their combination) and the three splits (Mid-Range, Median, Mean). In cases where the split only results in two types of areas (high/low) we examine with a t-test how different the areas with high values are from the low, in relation to the number of people they attract. In cases where the split results in more types (high Connectivity–low VMD/high Connectivity–high VMD, etc.) we test whether the different types differ with an ANOVA. The tests are all independent given that we are examining non-paired populations of different sizes.

We test across the aforementioned dataset by grouping all the areas found in all sites along with their respective densities of people. This way we examine whether patterns can be found that are generic and valid for all types of spaces. We also apply this methodology on a case-by-case basis in order to understand whether it is reliable for an architect to use these tests within a specific project.

As we can see from the histogram below (Figure 13.9), the distribution of the density in each area is heavily skewed to the right. This is a standard effect encountered when working with count data and can be countered by taking the logarithm of the number in question.

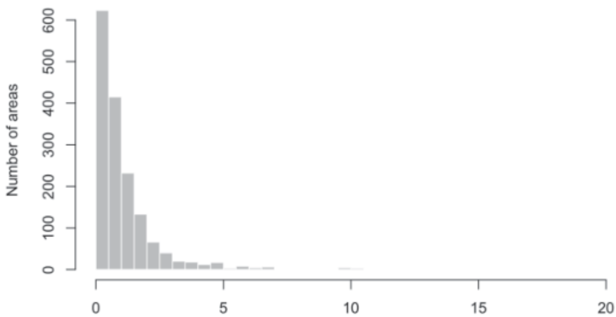

Figure 13.9

Numbers of areas split by the combination of the means of Connectivity and Visual Mean Depth, grouped by the density of people they attract.

The overall results of the tests for the density of people moving can be seen in Table 13.1 below. Independently of the split used all the tests are significant. Also, independently of the split we find that the order of the types in relation to the amount of people moving remains stable. This means that when the split is with Connectivity, areas with low values attract fewer people, specifically we observe around half the density. When the split is with Visual Mean Depth, areas with low values attract more people, around one and a half the density seen in areas with high values. The results for the combined metric are also relatively consistent, with the lowest density of people seen in areas with low connectivity and high mean depth, followed by low connectivity and low mean depth. The last two groups (high connectivity–low mean depth, high connectivity–high mean depth) seem to be interchangeable depending on the splitting method, but the split by the mean seems to be more reliable as it has a slightly higher R^2 value and more significant cases when those are examined one by one (see Table 13.2).

Table 13.2 shows the p-values of the tests on a case-by-case basis, ordered by the number of people counted in each case. While a few cases show significant results, none of the splits works reliably for all. Most of the cases that follow the general rule seem to be the larger cases pointing perhaps to a requirement for the project to have a critical mass to accurately extract such results. The scenario that best fits most cases is Connectivity split by the mean, followed by the various cases split by Visual Mean Depth. We also ordered (but not show) the table by the average mean depth of each site, average connectivity and number of teams created, but they did not seem to reveal useful patterns.

The same two tables follow for interaction. For this behaviour, the general results (Table 13.3) are not as consistent, with only two scenarios appearing significant: Connectivity split by the median and the combined metric split by the means. In the former scenario low connectivity areas were found to attract around 80% fewer people interacting; in the latter, the fewer people interacting were found in low connectivity, low Visual Mean Depth areas. These are areas quite central to the building but without a lot of visible space. The two intermediate types of areas (low connectivity–high Visual Mean Depth and high connectivity–low Visual Mean Depth) were found to attract about the same amount of people interacting.

The greatest densities of people interacting were found to be in areas of high connectivity and high Visual Mean Depth, areas that are large but not very central to the building. The combined metric by mid-range also provides significant results but, as mentioned previously, the areas created are greatly imbalanced when Visual Mean Depth is considered; therefore, it is only shown here for completeness.

	Connectivity Mid-Range	Connectivity Median	Connectivity Mean	VMD Mid-Range	VMD Median	VMD Mean	Connectivity-VMD Mid-Range	Connectivity-VMD Median	Connectivity-VMD Mean
p-value	0.000	0.000	0.000	0.000	0.006	0.009	0.000	0.000	0.000
t or R^2	-6.874	-6.770	-6.565	3.987	2.745	2.636	0.022	0.021	0.025
Ordered types	L, H	L, H	L, H	H, L	H, L	H, L	LH, LL, HH, HL	LH, LL, HH, HL	LH, LL, HL, HH
Means	0.26, 0.46	0.24, 0.39	0.23, 0.41	0.22, 0.30	0.27, 0.34	0.29, 0.36	0.27, 0.28, 0.31, 0.45	0.25, 0.30, 0.31, 0.43	0.24, 0.29, 0.37, 0.43

Table 13.1

T-tests and ANOVAs for overall movement (L for Low, H for High, Means in number of people per m^2 per hour).

	Number of people	Connectivity Mid-Range	Connectivity Median	Connectivity Mean	VMD Mid-Range	VMD Median	VMD Mean	Connectivity-VMD Mid-Range	Connectivity-VMD Median	Connectivity-VMD Mean	Significant tests
All	91310	0.000	0.000	0.000	0.000	0.006	0.009	0.000	0.000	0.000	9/9
67	137							0.922	0.629	0.887	0/3
28	315				0.466	0.498	0.489	0.994	0.992	0.948	0/6
17	357	0.015	0.036	0.014	0.043	0.335	0.404	0.167	0.682	0.148	4/9
32	379		0.088	0.372	0.024	0.514		0.024	0.551	0.776	2/7
65	453		0.135	0.629	0.807			0.916	0.848	0.827	0/6
54	504	0.005	0.006	0.002	0.074	0.375	0.137	0.051	0.058	0.076	3/9
85	571		0.479	0.943		0.042	0.075		0.434	0.053	1/6
25	604	0.166	0.625	0.578	0.003	0.875	0.554	0.323	0.255	0.264	1/9
47	733	0.418	0.202	0.225	0.156	0.140	0.284	0.832	0.142	0.607	0/9
66	735	0.466	0.386	0.191	0.886	0.219	0.525	0.369	0.322	0.386	0/9
23	808	0.074	0.495	0.933	0.526	0.754	0.862	0.331	0.995	0.903	0/9
57	834	0.063	0.145	0.063	0.573	0.870	0.994	0.219	0.591	0.592	0/9
46	887	0.333	0.085	0.069	0.802	0.717	0.821	0.601	0.681	0.487	0/9
44	920	0.729	0.401	0.710	0.585		0.324	0.990	0.469	0.658	0/8
63	925		0.647	0.731	0.210	0.065	0.185	0.582	0.323	0.505	0/8
24	1001	0.688	0.156	0.080		0.506		0.007	0.049	0.000	3/7
27	1010	0.456	0.189	0.515	0.334	0.312	0.390	0.766	0.609	0.062	0/9
71	1480	0.851	0.371	0.717	0.681	0.534	0.494	0.783	0.060	0.120	0/9
29	1521	0.129	0.515	0.079	0.024	0.018	0.019	0.059	0.063	0.052	3/9
11	1635	0.003	0.579	0.012	0.003	0.004	0.001	0.014	0.006	0.003	8/9
37	1688	0.007	0.213	0.031	0.005	0.018	0.002	0.002	0.001	0.000	8/9
80	2023	0.892	0.550	0.041	0.255	0.756	0.034	0.329	0.904	0.035	3/9
73	2049		0.000	0.023		0.044	0.385	0.792	0.005	0.001	5/7
18	2197	0.105	0.727	0.394	0.977	0.027	0.089	0.269	0.039	0.201	2/9
45	2568	0.917	0.675	0.709	0.182	0.001	0.014	0.720	0.209	0.843	2/9
61	2871	0.191	0.037	0.014	0.230	0.259	0.429	0.343	0.027	0.030	4/9
49	3279	0.471	0.738	0.692	0.286	0.389	0.107	0.412	0.285	0.440	0/9
50	3309	0.553	0.553	0.194	0.092	0.051	0.030	0.688	0.662	0.034	2/9
51	4888		0.277		0.264	0.776	0.036	0.062	0.348	0.006	2/7
36	5748	0.000	0.000	0.000	0.004	0.033	0.025	0.000	0.000	0.000	9/9
75	9074	0.002	0.044	0.038	0.120	0.502	0.710	0.000	0.030	0.045	6/9
58	9844	0.686	0.057	0.130	0.000	0.180	0.311	0.085	0.931	0.988	1/9
68	10579	0.007	0.113	0.114	0.051	0.085	0.273	0.182	0.023	0.175	2/9
84	15384	0.010	0.003	0.021	0.295	0.088	0.232	0.168	0.801	0.774	3/9
Significant		8/26	7/32	10/31	8/30	8/31	8/30	6/33	9/34	10/34	74/281

Table 13.2

T-tests and ANOVAs for movement per site (p-values); empty cells are cases where the number of groups were insufficient to run the test.

	Connectivity Mid-Range	Connectivity Median	Connectivity Mean	VMD Mid-Range	VMD Median	VMD Mean	Connectivity-VMD Mid-Range	Connectivity-VMD Median	Connectivity-VMD Mean
p-value	0.197	0.017	0.351	0.909	0.425	0.055	0.043	0.365	0.000
t or R^2	-1.295	-2.412	-0.935	0.114	-0.800	-1.927	0.007	0.002	0.013
Ordered types	L, H	L, H	L, H	H, L	L, H	L, H	HH, LL, LH, HL	LL, LH, HL, HH	LL, LH, HL, HH
Means	0.64, 0.73	0.58, 0.71	0.58, 0.64	0.62, 0.63	0.61, 0.66	0.66, 0.79	0.55, 0.64, 0.73, 0.85	0.60, 0.65, 0.68, 0.68	0.53, 0.66, 0.67, 0.80

Table 13.3

T-tests and ANOVAs for overall interaction (L for Low, H for High, Means in number of people per m^2 per hour).

In the case-by-case table below (Table 13.4) it is evident that while we can detect significant generic patterns in the overall data, when we examine each site, the results are not as clear. While more people were counted interacting, in contrast to movement they don't appear to prefer specific spaces. There also does not appear to be a relationship between the size of the study and whether it shows significant results.

	Number of people	Connectivity Mid-Range	Connectivity Median	Connectivity Mean	VMD Mid-Range	VMD Median	VMD Mean	Connectivity-VMD Mid-Range	Connectivity-VMD Median	Connectivity-VMD Mean	Significant tests
All	199062	0.197	0.017	0.351	0.909	0.425	0.055	0.043	0.365	0.000	3/9
67	422								0.907	0.720	0/2
17	785	0.741	0.548	0.486	0.817	0.141	0.417	0.995	0.576	0.671	0/9
28	877							0.771	0.367	0.973	0/3
54	912	0.347	0.245	0.286	0.010	0.311	0.540	0.136	0.351	0.598	1/9
46	1089	0.181	0.488	0.042	0.213	0.726	0.950	0.818	0.773	0.434	1/9
25	1119	0.172	0.547	0.340	0.433	0.052	0.591	0.760	0.473	0.199	0/9
32	1121		0.237	0.322	0.873	0.650		0.526	0.164	0.208	0/7
65	1327		0.591	0.193	0.276		0.567	0.907	0.951	0.987	0/7
85	1771		0.392	0.378		0.436	0.965	0.963	0.315	0.297	0/7
44	1815	0.250	0.634	0.590	0.258		0.603	0.377	0.255	0.924	0/8
47	1819	0.365	0.772	0.712	0.559	0.178	0.714	0.486	0.965	0.896	0/9
66	1846	0.784	0.431	0.748	0.252	0.016	0.690	0.470	0.703	0.582	1/9
57	2181	0.000	0.135	0.000	0.232	0.000	0.000	0.469	0.009	0.236	5/9
63	2411		0.392	0.291	0.534	0.574	0.525	0.388	0.724	0.340	0/8
23	2450	0.431	0.369	0.147	0.370	0.020	0.009	0.768	0.035	0.002	4/9
73	2564		0.184	0.961	0.961	0.005	0.580	0.011	0.003	0.001	4/8
24	2848	0.527	0.398	0.340		0.313		0.065	0.093	0.162	0/7
11	2934	0.504	0.028	0.002	0.406	0.007	0.007	0.907	0.016	0.023	6/9
27	2965	0.617	0.911	0.773	0.629	0.480	0.265	0.831	0.508	0.361	0/9
29	3244	0.450	0.105	0.241	0.567	0.464	0.887	0.202	0.161	0.629	0/9
37	3566	0.015	0.456	0.083	0.643	0.285	0.242	0.415	0.142	0.149	1/9
80	3692	0.658	0.385	0.676	0.013	0.813	0.003	0.020	0.375	0.018	4/9
18	4255	0.115	0.242	0.498	0.729	0.403	0.809	0.840	0.470	0.909	0/9
45	4928	0.317	0.350	0.811	0.012	0.641	0.367	0.071	0.394	0.662	1/9
71	5181	0.372	0.745	0.687	0.111	0.514	0.571	0.269	0.017	0.394	1/9
61	6905	0.582	0.533	0.989	0.506	0.870	0.961	0.732	0.161	0.275	0/9
50	7151	0.930	0.930	0.888	0.088	0.194	0.871	0.821	0.767	0.984	0/9
49	7523	0.821	0.124	0.796	0.867	0.916	0.654	0.972	0.340	0.531	0/9
36	9367	0.925	0.132	0.343	0.558	0.044	0.145	0.092	0.007	0.141	2/9
51	10067		0.890			0.033	0.245	0.918	0.723	0.228	1/6
75	18090	0.002	0.247	0.216	0.806	0.053	0.555	0.051	0.892	0.313	1/9
58	19726	0.679	0.448	0.815	0.111	0.260	0.002	0.870	0.669	0.230	1/9
68	21544	0.008	0.355	0.889	0.847	0.626	0.977	0.136	0.214	0.474	1/9
84	40567	0.169	0.435	0.295	0.545	0.525	0.935	0.159	0.002	0.000	2/9
Significant		4/26	1/32	3/31	3/29	7/30	5/30	2/33	7/34	5/34	37/279

Table 13.4

T-tests and ANOVAs for interaction per site (p-values); empty cells are cases where the number of groups were insufficient to run the test.

Discussion

The statistical tests show that the suggested representation is useful in the search for patterns of human behaviour in spatial configurations. The larger unit of analysis (area) avoids the problem of observed behaviour happening at very specific locations as seen in our previous research[16] by aggregating those observations and thus reducing the noise in the sample. We also manage to capture sufficient detail to differentiate between various spatial configurations, e.g., large and small spaces, central and non-central ones, as well as spaces that have combinations of those properties.

This method specifically allowed us to identify the predictability of the two examined behaviours. Movement proved to be the more predictable of the two, even in disproportionate splits of the sample (e.g., with the mid-range). Interaction on the other hand seems much more scattered perhaps as a result of the influence of other parameters. The placement of various functions (kitchens, workspaces) attracts movement but not necessarily interaction which may happen anywhere. Interaction is also influenced by the social network of the office, thus making spatial factors less relevant.

The results about movement contradict previous findings in a smaller sample (seven offices) by Hillier and Grajewski,[8] that movement increases in more segregated areas. Instead, we found that movement happened in central spaces, especially those that were highly visible. This contradiction, as well as the overall findings in both the studied behaviours highlight the value of sampling from a large dataset. It provides a critical mass of data that allows us to identify generic patterns that are otherwise unattainable with small studies. It also allows smoothing out the various idiosyncrasies of specific studies, such as the locations of the various areas and distortions in the data. But most of all, it provides a basis on which we can identify which of these idiosyncrasies are actually pervasive in the sample and can be modelled and studied later on.

The large differences of means we find in the movement point to interesting possibilities for a designer. While not true for each individual case, it can be expected that areas with less visibility (low Connectivity) and those that are deeper in a building (high Visual Mean Depth) will attract fewer people moving. The combined metric provides some more nuance, in that we can expect most of the movement in a newly designed building to be found in highly visible, and central spaces. These results can be used as evidence to strategically inform future design decisions for example allowing a designer to specifically configure a space so as to attract more movement and interaction.

Conclusion and Future Work

In this study we examined the existing spatial representations of indoor space as vehicles to understand the patterns of human behaviour. We found that the existing representations can either not accurately represent indoor spaces, are ambiguous in their construction or do not provide a general enough unit of analysis. We proposed a new representation based on Visibility Graph Analysis that addresses this problem by creating larger units of analysis and allowing us thus to meaningfully compare spatial configuration and human behaviour. The unit proposed is an aggregation of the cells of the VGA lattice grid into similar and continuous areas that may then be used to aggregate the discrete observations of human presence.

We initially tested this representation on simple-shaped spaces to understand its output, but eventually evaluated it against a sample from a large dataset of office spaces that we used in previous studies. The results allowed us to identify generic patterns, true for the general set of office spaces, for two behaviours that of people moving, and people interacting. Movement was found to be consistently concentrated in places that are more visible or those that are more central to the building. Interaction on the other hand was only found to be predictable when visibility and centrality were examined together, with the most interactive areas being the ones with high visibility but which are not very central.

While our evaluation focused on office spaces the results of the analysis may be carried out to other types of indoor spaces. Given that office spaces are moderately programmed, we would expect this to perform worse for more strongly programmed spaces such as hospitals. The best fit might be loosely programmed spaces where the human behaviour is governed mainly by the configuration, such as museums and small-scale urban spaces such as public squares.

In the future we plan to more closely examine the cases one by one and identify the confounding factors and idiosyncrasies that make some of our results insignificant. We will incorporate other spatial information such as the locations of functions and desks as well as non-spatial data such as the office social network and other organisational parameters. We also plan to test the multitude of different metrics that have been created within the field of Space Syntax through the years, including, sets of topological, isovist, metric, and angular metrics that capture local and global properties of the space. Finally, in search for more elegant solutions we will compare the above mentioned to ones that are agnostic to existing metrics but select continuous areas in random or uniform ways.

References

1. Allen, Thomas John and Fustfeld, Alan R. “Research Laboratory Architecture and the Structuring of Communications”. In: R&D Management 5.2 (1975), pp. 153–164.
2. Backhouse, Alan and Drew, Peter. “The Design Implications of Social Interaction in a Workplace Setting”. In: Environment and Planning B: Planning and Design 19 (1992), pp. 573–573.
3. Benedikt, Michael L. “To Take Hold of Space: Isovists and Isovist Fields”. In: 6.1 (1979), pp. 47–65. ISSN: 0265-8135. DOI: 10.1068/b060047.
4. Cattuto, Ciro et al. “Dynamics of Person-to-Person Interactions from Distributed RFID Sensor Networks”. In: PLoS ONE 5.7 (July 15, 2010). Ed. by Neylon, Cameron, e11596. ISSN: 1932-6203. DOI: 10.1371/journal.pone.0011596.
5. EBD. The Knowledge Problem as Architects and Designers, What Do We Know about People? Aug. 22, 2015.
6. Greensted, Andrew. Blob Detection - The Lab Book Pages. Nov. 18, 2009.
7. Hatch, Mary Jo. “Physical Barriers, Task Characteristics, and Interaction Activity in Research and Development Firms”. In: 32.3 (Sept. 1987), p. 387. ISSN: 0001-8392. DOI: 10.2307/2392911.
8. Hillier, Bill and Grajewski, Tadeusz. “The Application of Space Syntax to Work Environments inside Buildings: Second Phase: Towards a Predictive Model”. In: Unit for Architectural Studies. London: The Bartlett School of Architecture and Planning, University College London, 1990.
9. Hillier, Bill and Hanson, Julienne. The Social Logic of Space. Cambridge University Press (CUP), 1984. ISBN: 978-0-511-59723-7.
10. Kabo, Felichism et al. “Shared Paths to the Lab A Sociospatial Network Analysis of Collaboration”. In: Environment and Behavior 47.1 (2015), pp. 57–84.
11. Kabo, Felichism et al. “Zone Overlap and Collaboration in Academic Biomedicine: A Functional Proximity Approach to Socio-Spatial Network Analysis”. In: Ross School of Business Paper 1184 (2013).
12. Koutsolampros, Petros et al. “Spatial Databases: Generating New Insights on Office Design and Human Behaviours in the Workplace”.

In: Proceedings of the 10th International Space Syntax Symposium. 10th International Space Syntax Symposium. London, 2015.

13. Outram, Christine. Part Two: What Starbucks Gets That Architects Don't. Or What Architects and Others Think of the Architecture Profession. July 5, 2015.
14. Peponis, J et al. "On the Description of Shape and Spatial Configuration inside Buildings: Convex Partitions and Their Local Properties". In: 24.5 (1997), pp. 761–781. ISSN: 0265-8135. DOI: 10.1068/b240761.
15. Sailer, Kerstin and Penn, Alan. "Spatiality and Transpatiality in Workplace Environments". In: Royal Institute of Technology (KTH), 2009.
16. Sailer, Kerstin et al. "Measuring Interaction in Workplaces". In: Architecture and Interaction. Ed. by Dalton, Nicholas Sheep et al. 2016.
17. Turner, Alasdair. "Depthmap: A Program to Perform Visibility Graph Analysis". In: Proceedings of the 3rd International Symposium on Space Syntax. Vol. 31. 2001, pp. 31–12.
18. Turner, Alasdair et al. "From Isovists to Visibility Graphs: A Methodology for the Analysis of Architectural Space". In: Environment and Planning B: Planning and Design 28.1 (Feb. 2001), pp. 103–121. ISSN: 0265-8135, 1472-3417. DOI: 10.1068/b2684.
19. Varoudis, Tasos. depthmapX–Multi-Platform Spatial Network Analyses Software. 2012.
20. Vaughan, Laura. Space Syntax Observation Manual (2001 Unpublished Revised Edition). 2001.

I.4

SCAVA Methodologies in Landscape Architecture

CHAPTER FOURTEEN

3D SPACE SYNTAX ANALYSIS: ATTRIBUTES TO BE APPLIED IN LANDSCAPE ARCHITECTURE PROJECTS[(1)]

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Introduction

Public space plays a major role in the quality of life of citizens. Many public spaces are green areas, rendering it essential to understand the relations and actions between people and the spaces they use, as well as how spatial elements in green areas influence these relations. In green areas, ground modelling, vegetation and time are the elements that promote these major interconnections. Together, these elements have an unequivocal impact on visibility, connectivity, and accessibility, offering different experiences to users and, to the same degree, granting different usages as time advances.

Space Syntax

Space Syntax[1] is a set of methods with an underlying set of theoretical assumptions, which methodology provides tools to analyse these linguistic characteristics of space—configuration, visual permeability and physical accessibility—and their functional relations to the physical, social and psychical environment. It has profound roots in classical architectural theory, but it has been developed in recent and formal languages since the 1970s. Although in dynamic progress, Space Syntax is already a proven and

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very well disseminated instrument in architectural and urban studies. Bafna[2] describes it as a research method that studies the relations between society and space from the perspective of a general theory of the structure of inhabited space in its various forms, meaning buildings, cities, landscapes, etc. It contains a large semantic network of quantified concepts, formally defined, such as isovist, connectivity, depth, integration, entropy, and controllability. For example, isovist is the "polygon created by delineating the area visible to an observer in that position, most often assumed as having a 360-degree field of vision".[2]

Space Syntax in Landscape Architecture

Current studies applying Space Syntax methods to Landscape Architecture demonstrate its current advantages in evaluating green spaces. Research has been developed in the sense of evaluating the effect of planting design in urban parks[5, 6], senior walking behaviour in urban parks[8], accessibility indicators and trail use prediction in natural parks[9, 10] and could influence the design process of green spaces. Green areas are different from buildings and the urban environment, since they do not have such clear and easy to define boundaries. Zhai and Baran[11] indicated general principles for applying 2D Space Syntax to urban parks, such as the definition of activity zones and walkways and compared them to their urban and architectural counterparts such as buildings and streets.

Although these are interesting analyses, it is considered that some parameters that could be applied to current software, to further study and analyse Landscape Architecture projects, are missing. In green spaces, topography and ground shaping, vegetation (Robinson, 2004) and time (Tebyanian, 2016) are the resources that the designer can use to promote their desired natural, human, and social functions. The relationship between these components influences the visibility, connectivity, and accessibility of spaces, resulting in different perceptions and uses over time. The application of Space Syntax methods in Landscape Architecture seems very promising but, nevertheless, its use has been very sporadic.

The design process is generally the same in architecture and landscape architecture. It starts from a general/conceptual view of the design and moves towards a more detailed final product where the configuration of space and materials is well defined. The choices made for a design are a result of experience and continuous study. Space Syntax as a tool that has been developed and studied throughout the years can provide an efficient method of aiding the design process. Dursun[12] explores the contribution of

Space Syntax in this endeavour presenting three case studies at an urban and architectural scale, and as a means of design education, concluding that it can be an efficient method of aiding in design choices through "evidence-based design" with various tools to evaluate design choices before-hand. Li *et al*.[13] further studied this matter with the addition of BIM (Building Information Modelling) showing it is an interesting means of developing the design at the same time that it is possible to analyse the outcomes and consequences of each choice. Both of these studies consider 2D analysis of space.

Three-Dimension Space Syntax

Although Space Syntax analyses mainly the 2D space, space is actually perceived in three-dimensions (3D). So, to fully be able to understand visibility in the urban space/architecture/green areas it would be interesting to add a third dimension. "Visibility represents the size of a space that people visually perceive and can also be referred to as the visual field, isovist, and view shed indexes"[14]. Schroder *et al*.[15] describe a methodology and implementation of 3D Space Syntax with the aim of creating a visibility surface that summarises the varying degree of visibility values among a set of buildings, but do not consider altimetry and the visibility surface on modelled buildings.

Kim *et al*.[14] introduced a set of concepts to take into account in 3D visibility analysis and experimented with an urban space and various combinations of building heights, showing that the heights of buildings gradually affect the spaces around them, but doesn't also consider altimetry of the terrain. These authors do not consider the complexity of vegetation in the urban space.

Morais *et al*.[16] introduced the notion of tree transparency in their paper on the 3D visibility analysis of Casa da Música, in Porto, and the surrounding areas, considering a difference in visual permeability of the tree crowns in summer and winter, showing relevant differences in the global visibility of the space, though these didn't consider real values of opacity and form for each tree species.

3D Space Syntax software—DepthSpace3D

In recent years, three-dimensional analysis has been focusing of research in the Space Syntax field, as is reviewed by Ruth and Conroy Dalton (2015). However, this had not yet materialised in the development of open-use software for three-dimensional Space Syntax analysis before DepthSpace3D [(2)] was released, expanding on concepts developed in Space Syntax theory, particularly those regarding augmented visibility graph analysis (VGA) (Varoudis and Penn, 2015). The research reported in this paper uses this software, as three-dimensional analysis seems to have some advantages over current two-dimensional syntactic analysis in situations which are particularly fitting to the study of landscape architecture, such as:

- Rough altimetry of the terrain, either natural or sought by the designer;
- Very dynamic volumetric geometries, in size, configuration, elevation and interpenetration, such as those created by vegetation;
- 3D analysis could very well be a powerful tool in formalising the classical theoretical and aesthetical space concepts such as proportions and scales, hierarchy, or rhythm.

DepthSpace3D developments for Landscape Architecture

This paper will explore how the integration of visibility analysis in the design process of a landscape project is able to produce useful results for the implementation of an iterative practice of project amelioration by using the DepthSpace3D software. To be able to apply this software to landscape projects and analyses, the authors believe it is necessary to define a set of attributes to be applied in ground modelling and vegetation, due to the underlying complexity of green areas. The paper will focus on the aforementioned attributes, expanding on the work of Morais *et al*.[16]

The use of DepthSpace3D software in landscape projects and analyses implies the selection of a set of attributes to be applied in ground modelling and vegetation.

The attributes proposed regarding terrain modelling were as follows: 1) levels and 2) forms. The attributes proposed regarding vegetation were: 1) Dimension; 2) Form; 3) Growth Speed and 4) Visual Permeability of the crown in winter and summer. These attributes translate changes in the vegetation through time. In addition to the attributes, a set of parameters have also to be defined to enable the assessment of changes in the vegetation

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[(2)] DepthSpace3D is a software developed by some of the authors of the present paper and is freely available at http://opoarch.com/ds3d download/ for academic use. How Space Syntax concepts were adapted for three-dimensional analysis was developed in earlier research by Morais (2018).

through time. A trial application of these attributes and parameters in the DepthSpace3D software was developed under an urban park landscape project. This exercise allowed for a deeper understanding of the applicability of this software on the planning, completion of the project and on the social behaviour understanding.

Dialectic Cross-Development of Landscape Architecture Analysis and Space Syntax 3D analysis

So, the main objective of this research was the promotion of a cross-development between the Landscape Architecture Analysis and the 3D Space Syntax analysis, provided by DepthSpace3D digital tool. The demands of the Landscape Architecture were introduced in the aforementioned software providing adaptation and improvement.

The spatial analysis provided by the digital tool formalising or giving new parameters for the development and parallel evaluation of design in Landscape Architecture, considering both its linguistic characteristics and its functional relations to the physical, social and psychic environment.

Materials and Methods

DepthSpace3D Model Creation

Firstly, it was necessary to delimitate the study area for model creation. It was considered important to study the relations between the interior and exterior of the park. This led to the inclusion of a broader area that extends beyond the limits of the project. This includes surrounding streets, structures, and vegetation.

The model developed in DepthSpace3D comprises three conceptual types of spaces—the viewed, the viewing and the obstacle spaces:

- The viewed space has 2 components—a) the ground, buildings and vegetation surfaces (physically identical to the obstacle spaces but conceptually different); b) the global volume, corresponding to the ‘air’ modelled by a three-dimensional grid, vertically ten meters apart; and horizontally three meters apart;
- The viewing space is the space where the viewing subjects can move, as opposed to the entirety of the studied volume;
- The obstacle (to visibility) space is modelled by the surfaces of the ground, considering the curved topography, the facades, and other

solid surfaces (buildings, trees, and large shrubs, etc.).

Methodology

It was first necessary to delimitate the study area for model creation. The study area is based on the plans for the project of the Urban Park in Maia–Porto, Portugal. It was considered important to study the relations between the interior and exterior of the park which led to the inclusion of a broader area that extends beyond the limits of the project.

Following the delimitation of the study area, it was considered important to evaluate which elements had to be present in the model. This specific case study has buildings present in the space that have to modelled, as well as altimetry differences and of course vegetation. Since Space Syntax analysis is usually 2D, it rarely or never considers the last two elements, making it necessary to define them in the context of DepthSpace3D. Attributes and parameters were then defined for terrain modelling and vegetation and are explained further in the subchapter 2.3.1.

Finally, the model was created taking into account the previously mentioned factors and analyses were made to evaluate and determine their interest in 3D Space Syntax analysis. The following diagram synthetises the followed methodology.

Figure 14.1

Methodology diagram.

Attributes and Parameters

Aiming to study the aforementioned instances in the context of Landscape Architecture, it was essential to decide on a set of attributes and parameters to apply to ground modelling and vegetation. The latter, due to the complexity that involves the natural development of plant life, had to be investigated to achieve a set of summarised concepts to be employed in the analysis. Plants are live and continuously evolving structures, showing great variability, affecting visibility and the use of space through time. These parameters enable the assessment of space considering time. To obtain a set of attributes and parameters for Landscape Architecture it was necessary, at an initial stage, to understand which could be applied to 3D Space Syntax analysis. To fulfil this endeavour, an extensive literature review to find the possible attributes and parameters to apply in the development of this software was undertaken. From this review, four attributes were selected to be applied for trees and large shrubs:

1. Dimension, involving three parameters: height, width and trunk height, defined by Moreira.[17] Trunk height is considered from the ground to the first branches.
2. Form, as defined by Moreira.[17] In order to avoid overburdening computational resources, the volumes/form were simplified to simple shapes, with or without a distinct trunk. Innumerous tree volumes/forms exist in nature, but to simplify 5 volumes/forms were chosen: conical, rounded, wide, pyramidal and columnar (Table 14.1).
3. Growth speed was considered as slow, medium and fast based on Viñas *et al*.[18] and Costa[19] considering the dimensions after 20 years of plant growth (Table 14.1).
4. The visual permeability of the crown in winter and summer was considered opacity applied to deciduous and evergreen plants. For the latter, the opacity values were considered the same in winter and summer. The method used for evaluating the permeability of the crown encompasses three phases:
   1) Picking images that represent naturally, well-developed adult specimens for each species;
   2) Determining crown transparency, adapting the methods of Clark, Lee & Araman[20] and Borianne *et al*.[21] consisting of a simple delineation of the crown, acquiring the total number of pixels (Tp) (100% of the crown area) and acquiring the visible light area through the crown (Sp) (number of pixels corresponding to the visible light/sky area, through the crown);
   3) Calculating visual permeability (P) through the formula:

$$P = 100 - \left(\frac{\mathbf{Sp * 100}}{\mathbf{Tp}}\right)$$

All these attributes were studied, quantified, and applied to a set of trees and large shrubs. The species of trees and large shrubs present in Table 14.1 were chosen considering the case study—Urban park in Maia, Porto.

Trees and large shrubs	Ultimate dimensions			Form	Growth speed Dimensions after 20 years			Visual permeability		
	Height (m)	Width (m)	Trunk height)	Classification	Classification	Height (m)	Width (m)	Classification	Summer	Winter
Alnus glutinosa	25	8	4	conical	fast	17	5	deciduous	83	49
Acer pseudoplatanus	30	25	4	rounded	slow	10	8	deciduous	88	60
Arbutus unedo	8	8	2	wide	slow	3	3	evergreen	92	92
Betula pendula	25	10	4	conical	fast	17	7	deciduous	76	44
Betula verrucosa	25	10	4	conical	fast	17	7	deciduous	76	44
Casuarina equisetifolia	20	8	4	conical	fast	13	5	evergreen	73	73
Cedrus libani	25	18	4	pyramidal	slow	8	6	evergreen	75	75
Cercis siliquastrum	10	10	3	wide	medium	5	5	deciduous	86	41
Chamaecyparis lawsoniana	40	5	-	pyramidal	fast	27	3	evergreen	99	99
Cupressus sempervirens 'sempervirens'	30	3	-	columnar	fast	20	2	evergreen	99	99
Frangula alnus	5	5	-	wide	fast	3	3	deciduous	83	62
Laurus nobilis	12	5	3	conical	slow	4	2	evergreen	83	83
Ligustrum japonicum	4	2,5	-	columnar	fast	3	2	evergreen	97	97
Liquidambar styraciflua	30	14	4	conical	fast	20	9	deciduous	81	23
Magnolia grandiflora	22	20	4	conical	slow	7	7	evergreen	87	87

Magnolia x soulangeana	10	8	4	rounded	slow	3	3	deciduous	86	34
Nerium oleander	6	3	-	wide	fast	4	2	evergreen	90	90
Melia azedarach	13	8	4	rounded	fast	9	5	deciduous	77	50
Olea europaea	15	10	3	rounded	slow	5	3	evergreen	87	87
Picea abies	40	6	-	columnar	fast	27	4	evergreen	87	87
Pinus pinaster	24	9	6	conical	fast	16	6	evergreen	77	77
Pinus pinea	25	14	6	wide	medium	13	7	evergreen	92	92
Prunus cerasifera “Pissardi”	8	8	3	rounded	fast	5	5	deciduous	84	46
Quercus coccinea	20	15	4	rounded	fast	13	10	deciduous	84	32
Quercus robur	35	22	4	wide	medium	18	22	deciduous	83	33
Quercus suber	15	20	4	rounded	slow	5	7	evergreen	76	76
Salix atrocinerea	6	5	-	rounded	fast	4	3	deciduous	85	46
Salix alba ‘Vitellina’	25	10	2	rounded	fast	13	7	deciduous	77	57
Ulmus procera	40	15	4	rounded	fast	27	10	deciduous	86	58

Table 14.1

Classification of trees present in the case study considering: 1) Dimensions (m) at maturity age; 2) Form; 3) Growth Speed and dimensions (m) after 20 years of development; 3) Visual permeability of the crown.

The 3D model was then created in the DepthSpace3D software (Figure 14.2), considering the attributes presented in Table1 4.1. It was modelled according to the project plans which include proposed vegetation and its attributes, ground modelling and the pre-existing structures such as buildings.

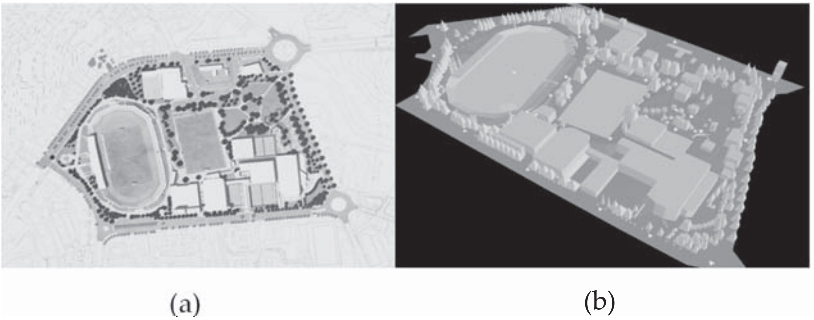


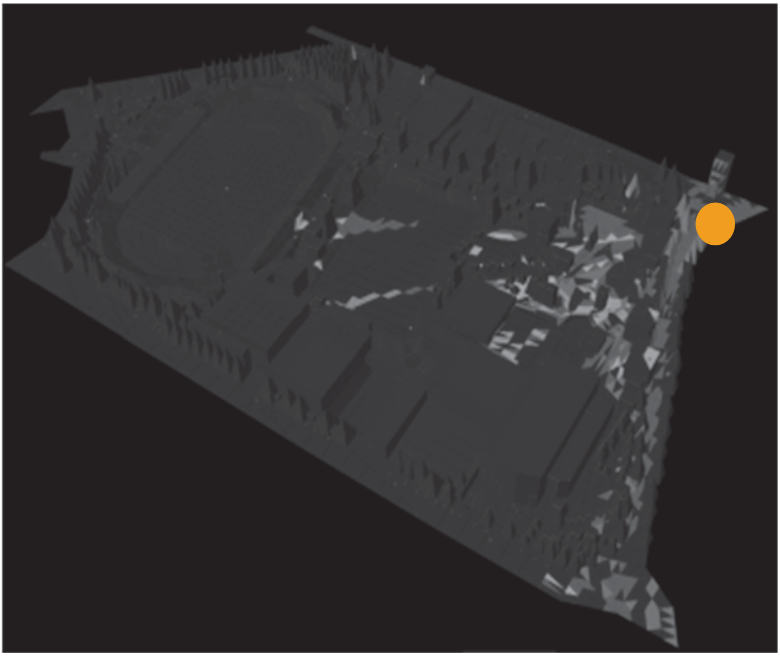
Figure 14.2

2D and 3D representations of the case study. a) Masterplan of the Maia Urban Park; b) Maia Urban Park 3D model built in the DepthSpace3D software.

Results

In Landscape Architecture, visualisations allow the user to view what the space can eventually become and what will be seen from a certain point of view. These visualisations try to represent what the space will become in the idea of the designer but fail to represent objectively what is seen throughout the space, as they are most of the times centred on the best views. In the trial application for the urban park, the question about what can be observed from the main entrance considering the terrain modelling and trees can be answered by an isovist with precision and ease of communication (Figure 14.2). The images present a gradient of colours that goes from dark blue to red which represent the amount of visibility on a certain location.

(a)



(b)

Figure 14.3

Complementary approach to the design process: a) 3D renderings from the main entrance; b) isovist from the main entrance

Dark blue colour indicates that the space has no visibility from the chosen points and red colour indicates that the space is very visible from the chosen points. One of the most important attributes related to vegetation is time. In Figure 14.3, it is possible to visualise the effects of time on the park's global visibility, by considering vegetation growth. The differences in visibility are clear, as vegetation grows the spaces appear more defined opening and closing different views of space, creating variability over time. Considering the importance of density and permeability of the trees and in an initial and global exercise, simulations were developed where it is possible to understand the influence of this attribute in visual connectivity. The presented results originate from inserted viewpoints which are predicted as important points and paths inside the park. These include notable viewpoints from higher points in the park and various paths on the park.

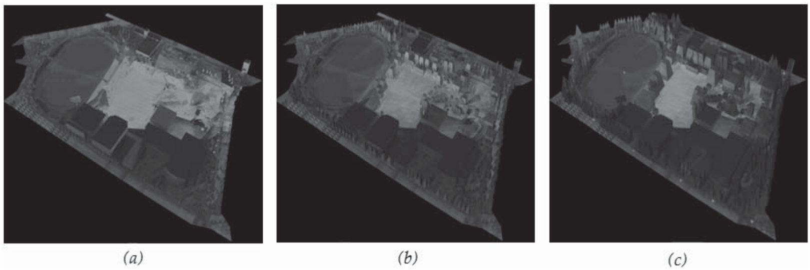


Figure 14.4

Visual connectivity maps of the effects of time in trees. a) initial growth; b) expected growth in 20 years; c) full growth.

The analysis also contributed to understand the spatial design. These analyses allow to determine if the objectives contemplated for the park are correct or if it is necessary to alter the design. Subtle manipulation of vegetation and topography could be experimented with until the design expectations were validated through visibility analysis, resulting in the final design. The case study of Maia Park (Figure 14.4) shows low levels of visibility from the interior to the exterior of the park but shows good visibility to the spaces inside of it, while not completely disclosing the whole park. It was also possible to verify in Figure 14.2 that the main entrance behaves as a logical entry, allowing high levels of visual permeability between the park and its immediate surroundings.

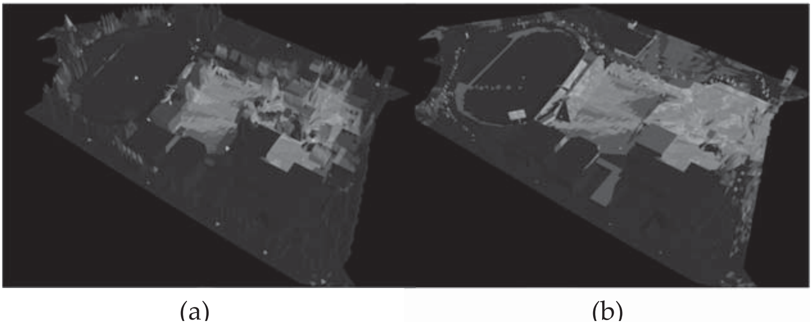


Figure 14.5

Visual connectivity maps of the effects of tree opacity in summer from the interior pathway. a) full growth; b) initial growth

The analysis also contributed to understanding how the trees and large shrubs will affect visibility throughout the year, by allowing to visualise the differences between summer and winter in the park's visibility. Although in some cases the differences are visible at ground level, they are most discernible at the higher points in space (Figure 14.5. a), d), c) and f)). This happens because the permeability is calculated through the crown of the trees. Visibility changes are most perceptible at ground level, when points that generate visibility are located at higher points in space (Figure 14.5 b) and e)).

Furthermore, visibility maps for additional zones were created (Figure 14.6) with the objective of understanding the definition of the designed spaces. During the project phase, it was the intention of the landscape architect that the park should not be grasped in its entirety from a single point but only through meandering inside the park. As it is perceptible from the images, this objective was successful. The spaces appear clearly defined, showing variations between high and low levels of visual connectivity, appealing to movement along the park.

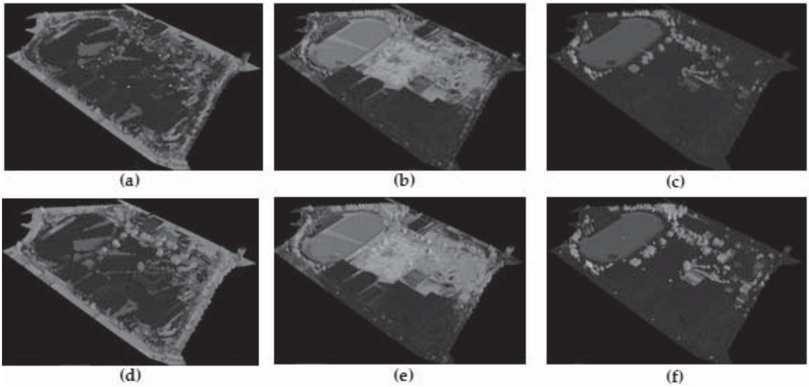


Figure 14.6

Visual connectivity maps of the effects on visibility of opacity in trees throughout the year, trees at 60% growth. a) from the exterior of the park in summer; b) from the interior of the park in summer; c) isovist from inside the municipal field in summer; d) from the exterior of the park in winter; e) from the interior of the park in winter; f) isovist from inside the municipal field in winter.

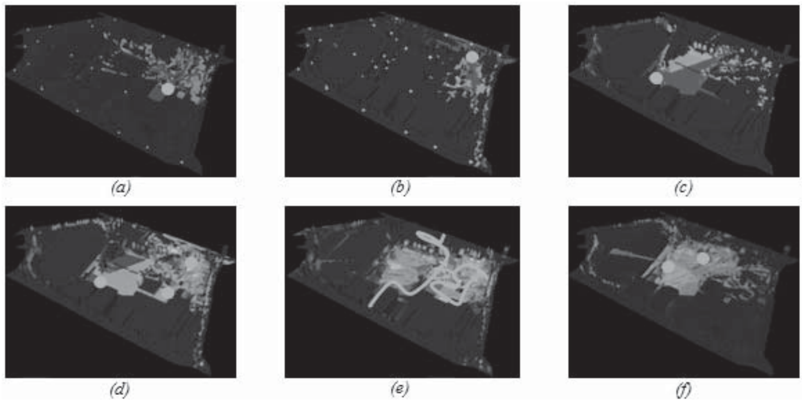


Figure 14.7

Visibility analysis of particular spaces and definition of differentiated spaces. a) isovist from the walkway; b) isovist from the gazebo; c) isovist from the bar; d) visibility from the 3 referential points: walkway, gazebo and bar; e) visibility from a meandering path in the park; f) visibility from the informal stands.

Conclusions

Space Syntax methodology allows for an immediate understanding of visibility, it proved effective in answering a series of questions about the initial design of the park—What do people see? What do people see more often? What do people see throughout the year? What do they see throughout time?

The experimental application of the attributes and parameters in the DepthSpace3D software allowed for an understanding of the interest of this software during the development of the Landscape Architecture project. It proved itself a useful tool, not only in studying and evaluating the effects of the final design, but also during project development. The software was developed along with the project, working to accommodate specific necessities that had not been foreseen.

While it is a process in continuous progress, the obtained results in the experimental application led us to believe that the attributes and parameters relating to terrain modelling and vegetation are of great interest, not only for Landscape Architects but also for a wide community of professionals of diverse areas in urban design.

The connection between analysis and design proved a useful step both towards the development of a successful design, and the furthering of a useful tool for Landscape Architecture. Future work should expand this even further. In addition, Space Syntax theory provides designers with other quantified concepts that relate to a spatial configuration for understanding expected movement and interaction in space which can contribute to understanding the designed spaces.

Further work should evolve to include a larger database of vegetation to be utilised inside the software allowing for a wider application of the software in other Landscape Architecture projects such as parks and gardens, but also in urban design to evaluate the effects of trees and topography on a three-dimensional spectrum at an urban scale.

References

1. Hillier, B., Hanson, J. *The social logic of Space*. Cambridge University Press: New York, Portugal, 1984, 978-0-521-23365-1
2. Bafna, S. Space Syntax: A brief introduction to its logic and analytical techniques. Environment and Behavior 2003, 35, 17-29, https://doi.org/10.1177/0013916502238863.
3. Benedikt, M. L. To Take Hold of Space: Isovists and Isovist Fields. *Environment and Planning B: Planning and Design* 1979, 6(1).
4. Turner, A. From isovists to visibility graphs: A methodology for the analysis or architectural space. *Environment and Planning B: Planning and Design* 2001, 28(1)
5. Mahmoud, A. H., (2011). Integrating Space Syntax Theory in Sustainable Planting Design of Parks. *Built and Natural Environment Research Papers*, 4 (1).
6. Mahmoud, A. H., Omar, R. H. Planting Design for Urban Parks: Space Syntax as a Landscape Design Assessment Tool. *Frontiers of Architectural Research 2015, 4*, 35-36, https://doi.org/10.1016/j.foar.2014.09.001.
7. Morais, F. DepthSpace3D: A New Digital Tool for 3D Space Syntax Analysis. In *Formal Methods in Architecture and Urbanism.* Cambridge Scholars Publishing, 2018.
8. Zhai, Y., Baran, P.K. Do configurational attributes matter in context of urban parks? Park pathway configurational attributes and senior walking. *Landscape and Urban Planning* 2016, 148, 188-202, https://doi.org/10.1016/j.landurbplan.2015.12.010.
9. Setola, N., Marzi, L., Torricelli, M.C. Accessibility Indicator for a trails Network in a Nature Park as Part of the Environmental Assessment Framework. *Environmental Impact Assessment Review* 2018, 69, 1-15, https://doi.org/10.1016/j.eiar.2017.11.003.
10. Zhai, Y., Baran, P.K., Wu, C. Can trail spatial attributes predict trail use level in urban forest park? An examination integrating GPS data and space syntax theory. Urban Forestry & Urban Greening 2018, 29, 171-182, https://doi.org/10.1016/j.ufug.2017.10.008.
11. Zhai, Y., Baran, P.K. Application of space syntax theory in study of urban parks and walking. Proceedings of the Ninth International Space Syntax Symposium 2013, 032:1-13.
12. Dursun, P. Space syntax in architectural design. Proceedings of the 6th International Space Syntax Symposium 2007, 056:01-12
13. Li, Y., Lertlakkhanakul, J. Lee, S., Choi, J. Design with space syntax analysis based on building information model: Towards an interactive

application of building information model in early design process. CAADFutures 2009, 502-514.

14. Kim, G., Kim, A., Kim, Y. A new 3D space syntax metri based on 3D isovist capture in urban space using remote sensing technology. Computers, Environment and Urban Systems 2019, 74, 74-87. https://doi.org/10.1016/j.compenvurbsys.2018.11.009
15. Schroder, C., Mackaness, W., Reitsma, F. Quantifying urban visibility using 3D space syntax. Proceedings of the Geographical Information Science Research UK Conference 2007, 359-366
16. Morais, F., Vaz, J.V., Viana, D.L., Carvalho, I.C., Ruivo, C., Paixão, C., Tejada, A., Gomes, T. 3D Space syntax analysis case study: Casa da Música. Proceedings of the 11th Space Syntax Symposium 2017, 169.1-16
17. Moreira, J. M. *Árvores e Arbustos em Portugal*. Argumentum: Lisboa, Portugal, 2008, 978-972-8479-59-6.
18. Viñas, F. N., Solanich, J. P., Vilardaga, X. A., & Montlló, L. *El Árbol en Jardinería y Paisajismo*. Ediciones Omega, S.A: Barcelona, Spain, 1992, 84-282-0878-6.
19. Costa, L. C. A vegetação na Implementação de Projetos de Execução em Arquitetura Paisagista. Caracterização e Definição de Critérios de Avaliação (Ph.D thesis). Faculdade de Ciências da Universidade do Porto, Porto, 2015.
20. Clark, N. A., Lee, S.-M., & Araman, P. A. (2003). Finding a good segmentation strategy for tree crown transparency estimation. Proceedings of the 19th Biennial Workshop on Color Photography, Videography and Airborne Imaging for Resource Assessment, Utah, United States of America, 2003; American Society for Photogrammetry and Remote Sensing.
21. Borianne, P., Subsol, G., & Caraglio, Y. Automated efficient computation of crown transparency from tree silhouette images. Computers and Electronics in Agriculture 2017, 108-118, https://doi.org/10.1016/j.compag.2016.12.011

CHAPTER FIFTEEN

THEORY APPLIED TO THE METHODOLOGY OF LANDSCAPE

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PAULO RENATO MESQUITA PELLEGRINO

Introduction

This paper discusses how to incorporate environmental issues into the urban planning and design according to the diversity of the problems related with the landscape. The focus is to highlight the issue of environmental planning from the perspective of landscape ecology and green infrastructure. Therefore, it assumes that the impacts of urbanization must be addressed in a multifunctional manner—i.e., considering urban, social, economic, and environmental infrastructure issues.

The vast literature in landscape ecology usually studies the impact of human intervention in non-urban areas. But, during the past decade, landscape ecology has made rapid strides in both theory and practice, and one of the recent advances in the field is to attempt to understand and predicting the ecological and environmental effects of urbanization on multiple scales[1]. In the last decades, ecology has awakened to urban areas as a legitimate habitat for study.[2] Thus, in order to consider the universe of landscape issues in a non-fragmented way, we argue that landscape ecology is an important contributor to better understand the urban ecology field. From this perspective, it is possible to admit an urban ecological science[3] in a transdisciplinary approach able to articulate different areas of knowledge by flexibilization between disciplines. It is important to produce a systemic, comprehensive, and transdisciplinary approach, which results in a differential analysis between conserving biodiversity, providing ecosystem services, and providing places for urban housing.[4] As a matter of fact, this approach toward urban areas fosters a consortium between researchers, public authorities, and civil society, and also contributes to promote a collaborative landscape science.

The paper discusses how to integrate the contents of the of ecology and landscape architecture into environmental planning through a methodology of the characterization and conformation of a network of urban open spaces. In addition to this introduction, it is organized into three chapters. Chapter I presents an orthodox ecological view from graph theory and least-cost paths. Chapter II examines a transdisciplinary approach by discussing the relation between the ecology of the landscape—e.g., theories related to graphs and least cost paths—with urban landscape planning. It also presents ways of applying this approach by understanding the open spaces as a multifunctional perspective. We will then present some final remarks.

Graph Theory

In this part, we will present the concepts related to the graph theory and the least-cost paths originating from surface resistance.

The usual ecological application of graph theory seeks to study the relationship between spatial configurations and the biodiversity. This theory was developed in the nineteenth century by Lenhard Euler and its main concern is studying the relations between the objects of a given set from structures called graphs. It was applied to Ecology by Urban and Keitt (2001), where it refers to the relationship between the mobility of species and ecological standards. Its use provides an analysis of the functional landscape in addition to its structural elements.

Graph-based approaches may more effectively bridge the gap between structure and function.[5] In other words, the theory provides a useful method to reduce complex landscapes into a knowable set of spatial configurations. Thus, this method uncovers patterns of interaction or flow, possibly creating a framework for the modelling of landscape fluxes.[6] According to Cantwell and Forman, in landscape ecological applications, a landscape is represented as a set of nodes (habitat patches) that are connected by links (e.g., via dispersal) resulting in a landscape graph.

In general, graphs conceptualize an entity as a set of points or "nodes" (vertices, points, sites) connected by edges or "links" (lines, edges, bonds) and, when node locations and connections are tied to specific spatial locations, the resulting feature is termed a spatial graph.[6, 7] In this perspective, we argue that the landscape is conceptualized in graphs as a network of nodes (fragments of vegetation) connected by links—flows of organisms and their ability to move from one node to another through the environment.[1] In the network pattern, the weights and roles of the nodes can be assigned based on qualitative and quantitative characteristics. Thereby, it can measure the importance of a node for the network, or the landscape and species' vulnerability in terms of their withdrawal. In this sense, it is possible to measure and study landscape connectivity.[4] From the graphs and their measured variables, a resistance surface[1] can also be realized. For instance, for any surface, a landscape can be represented as a grid in which each cell is assigned a resistance value based on the cost that it imposes on species movement.[5] According to Kupfer,[5] cost values reflect variables that are relevant for a particular species, such as vegetation cover type and structure, human infrastructure, and topography. Once a resistance surface has been calculated, the values are used to identify a path that minimizes cumulative costs between locations.[5] As an example, by incorporating estimates of mobility using species-specific least-cost surfaces, it becomes possible to quantify potential connectivity, as a proxy for how connected a given landscape or patch will be for a focal species.[8] As the least-cost distance calculated from the surface can be used to incorporate the effects of the landscape type ("matrix") on the movement of the species, we can transpose this model to better understand the urban environmental, as we will discuss in detail in the next part.

In Figure 15,1 it possible to see landscape represented by the dispersion capacity of the different species (750, 1000 and 1500m) with varying environmental permeability (agricultural and urban). In the second case, for species that can cross the environment, strategies such as steppingstones increase the permeability of the matrix and are more effective. In the third case, for species that are not tolerant (sensitive) to the urban environment, both the amount of habitat and their proximity do not positively influence in their biodiversity (e.g., wealth in a sample). Therefore, only a significant increase of the fragment areas associated with matrix permeability could benefit such species.[4]

[1] See McDonnel, 2011.

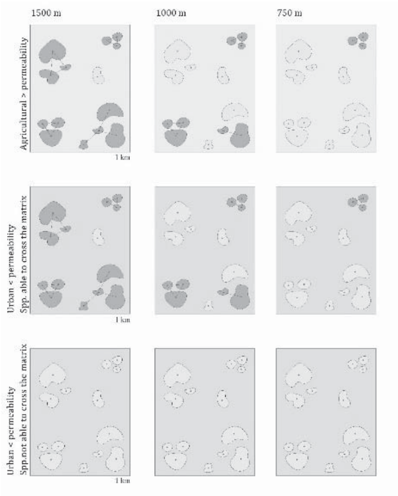

Figure 15.1

Landscape represented by the dispersion capacity of the different species.

Graph Theory Transposed to the Study of Urban Areas

As mention above, graph theory is a recent approach in ecology that promotes a methodological overcoming of the structural metrics (shape, size, distance) of the landscape by placing the questions related to the behaviour of the species in the analysis, considering the functionality of the matrix because it is not uniform for all of the community.[2]

In this second section, we argue the possibility of applying graph theory as a method for the urban landscape planning and design. This application can result in a multifunctional analysis of open spaces, which is able to value and integrate the political, cultural, ethical, and symbolic parameters of the landscape.

It is relevant to stress that the multifunctional meaning of open spaces has one of its origins in the North American proposal of Park Movement, whose precursor was Frederick Law Olmsted. From 1851 to 1895, this landscape

[2] This methodology arises from the substitution of purely descriptive and spatial structural indexes by indices that understand the landscape considering the species perception [9].

architect was responsible for the insertion of urban parks, of which Central Park York, 1858, was one of the pioneering examples.

Olmsted, influenced by English parks, developed his own thinking about the social function and structural insertion of green spaces in urban planning.[3]

Regarding the challenge of advancing methodologies that allow the study of open spaces based on their multifunctionality—encompassing urban, social, economic, and environmental infrastructure issues—we propose a concrete approach that contribute to enhance the decision-making in urban planning and management of open spaces.

An important reason for developing a methodology is related with the requalification of open spaces and the criteria applied in this process. Even with all the scientific and technical knowledge surrounding them, open spaces are still perceived via a reductionist approach, as they are almost always seen as a luxury aspect and not encompassing socio-environmental practices. Planners, urban planners, and architects end up using only socioeconomic criteria, disregarding natural basis and ecological relations.[12]

We argue that it is not only important to apply economic parameters for landscape planning and design, but also consider the social purpose of the open space, the pre-existences of the site, and to be attentive to the issue of the provision of ecosystem services.[4] Therefore, in which open spaces can we invest with multiple goals? And how do we measure the performance and multifunctionality of open spaces and the possibility of the simultaneous use of space, when considering their potential performance in the maintenance of ecological processes and/or social, cultural, and economic functions?

We discuss how to incorporate the complexity of socio and ecological systems into a spatial structure that is cohesive in landscape plans and projects. Even though spatial patterns in societies and economies are difficult to identify and value when translating them to a map. We argue that the application of graph theory in urban ecology contributes in this sense to the requalification and improvement of these open spaces. It is a question

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[3] The system of green areas interconnected by parkways reflects the systemic thinking of city organization from Olmsted, with the park as a structuring element. This movement was fundamental for the deployment of the green corridors in the United States [11].

(4) Both those related to support, provision and regulation as well as cultural ones.

of adopting a landscape ecology approach when thinking of a methodological model for landscape planning in cities.

The methodology to be suggested should present planning criteria for locating and inserting the green spaces in the urban territory that considers their social purpose and pre-existences. This method can be used to evaluate how environmental criteria influence the design of a network of open spaces. This association provides a framework to study and plan the urban territory in a spatial syntax manner, where urban green spaces are considered to be nodes of the graphs that are characterized and quantified by their connections and social accessibility, among other criteria.

The first step in least-cost path analysis is to identify core areas that serve as sources or destinations.[13] Thus, we can define some principles to establish the nodes for source and destinations. Different potential "nodes" can be studied: public parks (size, insertion in the territory, accessibility); green areas (size, pre-existence of vegetation, degree of access, and radius of influence) and their "links"; rivers and streams (opening of hidden, potential of urban flow corridor); and the road system (slope of roads, width of sidewalks, connecting element).

The values can be assigned to nodes and their links according to the presence and size of green areas, smaller road slopes, wider sidewalks, attraction elements (cultural and educational), the potential to create linear parks in rivers and streams, and many other criteria, which vary according to the purpose and location. In this sense, open spaces can be categorized according to their accessibility, function, form, and uses. For accessibility, it is necessary to analyse if it has public or private character and location. It is necessary to address what role they play in each period, to which society, and which scale and form when considering their function. According to its form, it needs to study its variations and historical period, as well as whether it is the result of planning, temporal adjustments, conservation, and social agents. Finally, in terms of its use, it is necessary to understand its users, when and how they use space, and who keeps it.[4]

After applying a resistance value to each of the selected nodes, it is possible to generate a total friction matrix[5] that represents the permeability of the focal urban landscape. This matrix can be expressed in a map by a resistance

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[5] This meaning was used for urban environmental planning in Jinan city, China [13]. The corridors were identified by the least-cost path method and the free space networks were designed based on graph theory and the gravity model.

surface that can be used to model least-cost paths for social and ecological purposes. Once calculated, least-cost distances can be directly incorporated into urban landscape graphs as an alternative to using the Euclidean distance to analyse and reflect how important is the node point. In this method, open space multifunctionality can be expressed by a resistance surface that, from an urban planning perspective, represents the distance between the social target points and the degree of the environmental and social impacts of the nodes from the graphs.

The resistance surface makes it possible to analyse which nodes (like green areas) have a greater resistance value for each variable and it also creates the potential for a network plan of open spaces. Also, it allows the multiple-way corridors between points of origin and target to be defined; for example, between local centralities and squares or where to increase the tree cover of the public green areas and to promote the connection between the areas that provide ecosystem services.

Finally, this is a method for understanding the dynamics of landscapes based on the establishment of criteria for investment selection and management in priority areas, both with a focus on protecting urban biodiversity and the redevelopment of spaces for social use.

Final Remarks

This paper presented how graph theory can contribute to urban environmental planning and, simultaneously, foster the field of urban ecology through the application of landscape ecology.

Regarding the application of graph theory, it has been highlighted in the analysis of the quantitative and qualitative aspects of the nodes and how it is possible to study the network of open spaces in a multifunctional manner. Multivariate analyses can contemplate the social and environmental integration of the city, specifically the areas of conflict between urban occupation and the legal administrative protection of natural resources.

We argued the importance of interpolating graph theory and resistance surfaces into the study of urban areas and promoting an assessment of the landscape in a multifunctional manner. This method permits the study of the dynamics of landscapes by establishing the criteria for the selection of investment and management in priority areas for the maintenance of ecological processes and social, cultural, and economic functions.

The main fact is that it is important to apply these theories, which are recurrent in the biological sciences, in landscape architecture simply because it allows a transdisciplinary understanding of the landscape. In addition, such methodology can be applied in urban planning since the attribution of nodes and their values of resistance can generate different surfaces for each approach and place.

The next step is to apply the methodology in a non-idealized territory.

References

1. Wu, J. 2013a. Key concepts and research topics in landscape ecology revisited: 30 years after Allenton Park workshop. Landscape Ecology 28. pp. 1–11.
2. Grimm, N.C.; Grove, J.M.; Pickett, S.T., Redman, C.L. Integrated approaches to long-term studies of urban ecological systems. BioScience, 2000, 50 (7). pp. 571–584.
3. Mcdonnell, M.J. The history of urban ecology: an ecologist's perspective. Urban ecology: patterns, processes, and applications. New York: Oxford University Press, 2011. pp. 5–13.
4. Sandre, A.F. O Planejamento Ambiental à luz da Ecologia da PaisagemEstudoAplicado da Zona de Amortecimento do Parque Estadual da Cantareira. São Paulo: Master in Science, São Paulo University, 2017. pp. 235.
5. Kupfer, J.A. Landscape ecology and biogeography: Rethinking landscape metrics in a post FRAGSTATS landscape. Progress in Physical Geography, 2012, n. 36. pp. 400–420.
6. Cantwell, M.D.; Forman R.T.T. Landscape graphs: ecological modeling with graph theory to detect configurations common to diverse landscapes. Landscape Ecology, 1993, n. 8, v.4. pp. 239–251.
7. Fall, A.; Fortin, M.J.; Manseau, M.; O'Brien, D., Spatial graphs: principles and applications for habitat connectivity. Ecosystems, 2007, 10. pp. 448–461.
8. Calabrese, J.M.; Fagan, W.F. A comparison-shopper's guide to connectivity metrics. Frontiers in Ecology and the Environment, 2004, v.2. pp. 529–536.
9. Metzger, J.P.W. Como lidar com regras pouco óbvias para conservação da biodiversidade em paisagens fragmentadas. Natureza & Conservação, 2006, v. 4, n.2. pp.11–23.
10. Ignatieva, M. et al. How to Put Nature into Our Neighbourhoods.

Application of Low Impact Urban Design and Development (LIUDD) Principles, with a Biodiversity Focus, for New Zealand Developers and Homeowners. Landcare Research New Zealand, 2008.

11. Lima, M.C; Schenk, L.B.M. Rios e Cidade: Processos de construção da forma urbana de São Carlos, SP. In: XI Colóquio QUAPA SEL, Sistema de Espaços Livres, 2016, Salvador. XI Colóquio QUAPA SEL, Sistema de Espaços Livres: Transformações e Permanências no Século XXI, 2016.
12. Pellegrino, P.R.M; Guedes, P.P.; Pirillo, F.C.; Fernandes, S.A. Paisagem da borda: uma estratégia para a condução das águas, da biodiversidade e das pessoas. In: COSTA, L.M.S.A. (Org.). Rios e paisagem urbana em cidades brasileiras. Rio de Janeiro: Viana & Mosley, PROURB, 2006. pp. 57–76.
13. Kong, F.; Haiwei, Y.; Nobukazu N.; Yueguang, Z. Urban green space network development for biodiversity conservation: Identification based on graph theory and gravity modeling. Landscape Urban Plan, 2010, n. 95. pp.16–27.

I.5

Dialogues with "Classical" Analysis in Architecture

CHAPTER SIXTEEN

FORM AND MEANING IN ARCHITECTURE AND URBANISM: PRINCIPLES OF QUALITY

JAVIER POYATOS SEBASTIÁN

Introduction

I would like to reflect on the understanding and experience of form with you. Let us understand form as the exterior sensitive presence of a reality. Then we can speak about form in architecture and urbanism.

Aristotle, in his work *Metaphysics*, distinguished form in natural elements from form in works of art. In works of art, form exists in the human soul before becoming material: "things whose form is in the soul are developed artificially" affirms the Greek philosopher. Form, for Aristotle, according to Erwin Panofsky,[1] implies Plato's idea in some way.

Ignazio Gardella expressed the following once during his brilliant architectural career: "Here I understood that form rises out of idea more than of function, that we must speak of form-idea more than form-function". From his viewpoint, Alberto Campo Baeza understands architecture as *constructed idea*. Therefore, form in works of art and in architecture is invented in the soul of the creator. But architectural form should have a consistent meaning. The meaning of an architectural form should be its correct adaptation to the objective of human habitat, according to the corresponding uses in each case, whether a home, a museum, or a temple. This should be the primary meaning that the architect looks for with the *raison d'être* of the architectural work being its ontological meaning. Form should then reach a dimension of benefit, of being "good for something". Form has to be "good for inhabiting" in the case of architecture. In this way, form grows out of the author's intention that gives it part of the meaning. The author's intention can also include usage, with customer requests, or may not include usage and still be satisfactory. It can also include many more aspects in addition to strictly function.

The architect's idea can be very wide-ranging; there is not only one architectural response to the program of usage in a building. We find ourselves before the creative dimension of the architect that develops intelligence, intuition, sensitivity, and even art, in an open and unpredictable form: imagination, dreams, and the subconscious, etc. The creation would be even more unpredictable if the author is a genius. Each architect has his own intimate significance. The architect's specific *vital energy* and *creative flair* must be recognized, to use the expressions by Emmanuel Mounier. That is to say, we have to consider the architect's personal response to provocations from the cultural environment and from history. In short, as Ortega y Gasset[2] said, we must observe how the architect takes on his circumstances and gives specific meaning to his architectural forms.

The methods of form design in architecture can never be completely systematic or scientific, in the normal sense of the scientific term. There is unpredictability in the invented form that comes from the free creativity of the author and complicates the definitive systematization of form. Perhaps we are moving too deeply into the world of ideas and things, but not deeply enough into an inquiry into the human condition. On the other hand, the creator's concept does not drain the understanding of architecture and its significance, as Hans-Georg Gadamer[3] and contemporary hermeneutics have clearly indicated. The understanding and enjoyment of a building does not end with the intentions of the creating architect. The building communicates aspects to the inhabitant that were not necessarily foreseen by the architect. Form does not derive from function as it is normally understood by the reductionist vein since the Modern Movement. The eminent psychologist and art theorist Rudolf Arnheim have admirably discussed this for us in his work the dynamics of architectural form. For example, ancient classic decorum refers to what a building needs to be as an appropriate exercise of usage, including the decoration and symbolic dimension. Arnheim has wisely summed up several aspects of form that can communicate:[4]

> we ask ourselves if such a building really presents the necessary unity to be visually understood. We ask ourselves if its exterior aspect reveals the physical and psychological functions for which it was created; if it reflects the spirit that inspires it, or should it inspire the community; if it is at least the partial expression of the best of the intelligence and imagination of man.

Human spirit has the ability to perceive the expressive and symbolic value of forms, and the architect should develop a special sensitivity and intuition for this. In any case, this search for quality in architectural form is very relevant. The values of quality and excellence that come to us from the Ancient Greek civilization must be recovered. Quality exists when form successfully organizes a human situation physically and spatially, and when it generates objective and subjective satisfaction in the user, as well as physical and spiritual satisfaction. We should look into the universal basics of human perception that Arnheim indicates.

Studies based on shared experiences of quality are needed. We have to investigate the perception of the positive values of the expression of form through studies that are contrasted and even agreed upon among interested specialists that work on architectural form. Studies on the public reaction towards these positive values of expression of form must also be completed.

The condition that Leon Battista Alberti[5] established for architectural harmony will always be a guide for the perception of quality of form: such continuity that nothing can be added, taken away, or modified without damage.

Now, I would like to focus on the urban form.

It is common to verify the loss of quality in urban form during the 20th and 21st centuries, especially in the current globalization scenario and in comparison to previous centuries. On the contrary, in the historic city, especially in the heritage city, we can frequently appreciate a noticeable quality of urban form. Rudolf Arnheim has eloquently written about this current situation:[6]

> We observe unmistakable signs of weariness, lack of discipline and responsibility. The design of many buildings, furniture and garments is an example of this decadence. The most disgusting symptoms are translated into an extravagance without limits, vulgar tastes and to trivial thoughts. We are too prone to accept little and to abandon the definitive effort, without taking advantage of all the resources, and to ignore what used to be the condition sine qua non for worthy art. This insufficiency is reflected in the low quality of most of the works and in the lack of valid criteria for their approval in the mass media.

We want to highlight the absence of criteria.

On the contrary, the accuracy of values of quality is the role of architectural and urban criticism in their respective areas. The eminent Spanish theorist and art historian Enrique Lafuente Ferrari[7] said the following:

> In general terms, criticism is a subtle and mysterious ability to perceive the most intimate and valuable qualities in things, people or artworks. These qualities are sometimes apparent, and sometimes even hidden within a whirlpool of secondary and superfluous flaws. This perception of quality, this distinction between the secondary and the essential, is for me the most eminent critical ability, and indeed it is not only applicable to works of art.

Methodology

In the past, the quality of urban form developed from a sort of good sense and collective taste; it was slowly and deliberately preserved, which must nowadays be achieved in a conscious and refined way. The collective taste in urban form is not the same anymore, due to lack of sensitivity, an accelerated pace in urban transformations, and the priority of economic profit, etc. We must then develop disciplinary training in this area. Therefore, the research and identification of features of quality in urban form is relevant in order to have the corrective tools available in the face of this contemporary cultural loss. For this reason, the identification of these parameters of quality from a hermeneutic point of view is proposed; that is, principles capable of opening a certain horizon of understanding and enjoyment of a specific quality perspective, as well as the horizon of conscious creation. It is understood here that quality in urban form is always connected to the user and to urban life. Form has quality only when it is valuable functionally and aesthetically to the integrated experience of the user.

Firstly, as we said, attention must be paid to the splendid achievements in urban form in the past by analysing the diverse principles which produced that quality. This way we will understand and better value the city of the past. The history of architectural theory can help us in this sense by means of the principles that appear in many treatises and essays. These principles are the cornerstones of good practice and have greatly influenced the practice of architecture and urbanism during those historical periods. This is the way that principles, such as beauty, decorum, grace, decoration, and taste, appear. Then, it is possible to look at the treatises by Vitruvius, Alberti, or Palladio, but also the essays from the 18th and 19th centuries. This way we will be conceptually improving our critical vision of the past.

Both the urban form of the past and the historical treatises and essays present a combination of very valuable principles that should be expanded, along with other contemporary principles of quality extracted from the phenomenological and psychological experience of the city. If we go into in depth analysis and meditation, as Ortega y Gasset[2] said, of those principles of quality in urban form (beauty, elegance, and decorum, etc.), we can infer that they also open up other several diverse ways in the process of obtaining quality. We can call them subprinciples of quality. For instance, beauty is not singularly unique; on the contrary, it offers a wide range of distinguishable options, such as harmony, elegance, delicacy, refinement, and technical perfection, etc. Therefore, each of these aspects constitutes a subprinciple of beauty.

Now we are going to provide two testimonies that support the need for the qualitative detailing of the direction that we are developing. On one hand, Rudolf Arnheim[6] states,

> The qualities that convey human values can be described with considerable accuracy, but many of these descriptions cannot be quantitatively verified by means of measurement or recounting data. They share this trait with many other facts of the spirit and nature, and it does not prevent them from existing or being important.

However, on the other, Ernst Gombrich[8] confirms this idea:

> and this is what critics did in the ancient times, and what they have been doing ever since, that is, to analyse and to subdivide areas for its admiration, and to articulate the multiplicity of human experience within the canon.

The understanding of principles and subprinciples of quality in urban form is needed even more in order to verify real historical or current cases of urban excellence. It is necessary to study specific urban examples that demonstrate undoubtable quality in form. In this way, it is possible to create a catalogue of typological concreteness of form supported with cases from the principles and subprinciples of quality that have been analysed. In addition, a better understanding and evaluation of the city of the past and that of today, such as a critical profile of principles of excellence, can contribute to overcoming the poor quality of form in the contemporary city with new conceptual resources for projects. In this way, each principle offers a horizon of understanding and also of urban creativity.

The principles and subprinciples in turn can intersect, offering cumulative and transverse quality options. Therefore, what this paper hopes to offer is a relevant and structured hermeneutical tool for the analysis of urban form through its values of quality and excellence. This method is related to classical research of urban form. An example is the one performed by Gordon Cullen in *The Concise Townscape*[9] or that of Christopher Alexander in *A Pattern* Language.[10] These studies try to determine certain principles or concepts of form and their explanation with examples. The difference with these more general works is that here, in this presentation, the goal of these principles is to capture directly and specifically the aspects of quality in urban form. The principles or concepts are in turn ideal for use as keywords to consciously channel creativity in urban design.

Assessment and Analysis

We would like to initially set forth six principles of quality in urban form, without attempting to be exhaustive, and present them for critical contrast to be completed by other possible interested authors, together with a real city case history. Each principle contributes a type of value that is beneficial in terms of form.

22. Beauty:

    Using Thomas Aquinas' definition, *pulchrum est quod visum placet*, we will define beauty as that which is pleasing to contemplation by the spirit. Philosophy and aesthetics authors have documented many variants of beauty, or subprinciples, as we have called them here. The aesthetics expert Tatarkiewicz says,[11]

    > There have been numerous attempts at listing these varieties of beauty. An exceptionally full listing is found in Goethe. Among others he names such varieties as: profundity, invention, plasticity, sublimity, individuality, spirituality, nobility, sensitivity, taste, aptness, suitability, potency, elegance, courtliness, completeness, richness, warmth, charm, grace, glamour, skill, lightness, vitality, delicacy, splendour, sophistication, stylishness, rhythmicity, harmony, purity, correctness, elegance, perfection. This is an ample list, but it is hardly an exhaustive one, if only because it passes over dignity, distinctiveness, monumentality, luxuriance, poetry and naturalness.

23. Scale:

    Scale is the right size of urban form in relation to the inhabitants or users, so that it generates a sensation of functional and psychological comfort. Therefore, with the right scale, buildings and urban spaces can contribute to a sensation of welcome and sensitive dimensioning for citizens.

24. Grace:

    Grace is the cordial and agreeable aspect of urban form.

25. Pleasantness:

    Pleasantness is the assorted and stimulating aspect of urban form.

26. Decorum:

    This is the way urban form adapts to different purposes and social significances.

27. Identity:

    Identity is the connection between urban form and the identifying values of the community where it is located.

    Now we are going to address the subprinciples of beauty in urban form; that is, the multiple varieties of beauty present in urban form. The principle of beauty is that which possesses the largest quantity and diversity of subprinciples. Therefore, we will study it in detail and with special dedication in this presentation. Beauty, understood as the quality that pleases the spirit, is the most outstanding principle of quality. Consequently, it requires preferential attention due to its richness; an attention that beauty has received throughout history. Some relevant subprinciples of beauty will be explained now in a general way.

Harmony in Buildings:

Here we refer to a classical expression of beauty. It is the cohesion of diversity, based in some cases on relations of mathematical proportions and, in others, it is simply inspired by taste alone.

Harmony with the Natural Environment:

The city is integrated aptly and pleasantly with its surrounding natural environment.

Appropriate Presence of Nature Inside Urban Form:

Here we refer to parks, gardens, and fountains, etc., which are qualified in different ways in the urban landscape.

Chromatism for Well-Being:

Its goal is the citizen's happiness, which is achieved through the strong emotional value of colour.

Efficient Sequence of Spaces and Forms:

The perception of urban beauty is not only static, but also dynamic since the citizen moves through successive areas of the city.

Accomplished Essentiality:

Mere essentiality is not enough for beauty. Essentiality must be commendable.

Perceptual Clearness:

This affects the senses pristinely and immediately. It also refers to sheer geometries and to prime colours. This pure beauty was praised by Plato.

Cheerful Clarity:

This concept does not only refer to simple luminous clarity, but also to the perceptual clarity stimulated by visual delight.

Rhythm and Musicality:

These qualities lend fascination and energy to form.

Light Designs:

The play of light and shadow through dimmed light and soft shadow create atmospheres in the city at different times of day.

Manifestation of Life:

The communication of life through form is perceptually invigorating and transmits existential vigour as a vehicle of beauty.

Useful Eloquent Force:

This refers to power and intense and admirable communication.

Serenity of Form:

It is pleasing to the spirit, according to the taste of ancient Greeks.

Polite Delicacy:

Delicacy and courtesy are in themselves pleasing to the spirit.

Qualified Refinement:

This represents the design of the refined and the exquisite.

Elegance:

Elegance in itself is always a vehicle of beauty.

Humble Charm:

This is another vehicle of beauty and it is a characteristic of Zen aesthetics.

Wealth of Form:

This represents the abundance and qualified variety of diverse forms or the appropriate presence of decoration.

Freedom and Flexibility of Form:

Freedom and flexibility make forms natural and commendable.

Graceful Lightness:

It is a source of charm.

The Masterful Curve:

The curve has emotional repercussions and undoubtedly implies pleasure when it is skilfully executed.

Qualified Textures:

These are a source of interesting sensorial and psychological communication.

Technical Perfection in Construction:

This conveys evidence of good implementation and the corresponding experiential satisfaction.

Conclusions

Our final goal in this paper is to address quality in urban form, not through superficial intuitive attitudes, but from conceptually structured intuitions based on shared experiences of quality. In this way, a new conceptual perspective of research is opened up and offered to other researchers who are looking to achieve a certain critical consensuses, which is so needed today in order to confront a higher quality of form in contemporary cities.

References

1. Panofsky, E. *El significado en las artes visuales*. Alianza, Madrid. 1987.
2. Ortega Y Gasset, J. *Meditación de la técnica.* Diálogo, Valencia. 2012
3. Gadamer, H.-G. *Verdad y Método I*. Sígueme, Salamanca. 1997.
4. Arnheim, R. *Dynamique de la forme architecturale.* Pierre Mardaga, Bruxelles. 1986.
5. Alberti, L. B. *De Re Aedificatoria.* Akal, Madrid. 1991.
6. Arnheim, R. *La forma visual de la arquitectura.* Gustavo Gili, Barcelona. 2001.
7. Lafuente Ferrari, E. *La fundamentación y los problemas de la historia del arte.* Instituto de España, Valencia. 1985.
8. Gombrich, E. H. *Ideales e ídolos: Ensayos sobre los valores en la historia y el arte*. Debate, Madrid. 2004.
9. Cullen, G. 2001 *The concise townscape.* Architectural Press, Oxford. 2004.
10. Alexander, C. *A pattern language. Un lenguaje de patrones.* Gustavo Gili, Barcelona. 1980.
11. Tatarkiewicz, W. *Historia de seis ideas.* Tecnos, Madrid. 2007.
12. Sitte, C. *Construcción de ciudades según principios artísticos.* Canosa, Barcelona. 1926.

Chapter Seventeen

Architecture and the City

Susanne Komossa,[1] Olindo Caso, Roberto Cavallo, Esther Gramsbergen, Nicola Marzot

Introduction

Central in the work of the combined research group "Architecture and the City" (A&C) at the Faculty of Architecture and the Built Environment, Delft University of Technology, is the notion of *public realm,* as a lens to look at the (trans)formation of urban space and architectural form. It is based on the assumption that the *public realm* is at the core of what defines a city and that in the course of time public life is institutionalised and formalised in public buildings, urban blocks and urban spaces.

A broad historical perspective, including the changing definitions of public institutions due to social-cultural and economic developments, is important to anticipate the future of public buildings. In this respect the *public real*m, is seen as a prerequisite for the future of society, and at the same time, in retrospective, as society's architectural representation.

Within the A&C research the definition of the public realm is distinct from public space. It refers to an intermediate space of (ex)change of ideas, opinions, goods and labour, of discussion or even conflict (Hofland 1998). It enhances the public sphere as a whole as an abstract realm on one hand, and a defined physical domain on the other.

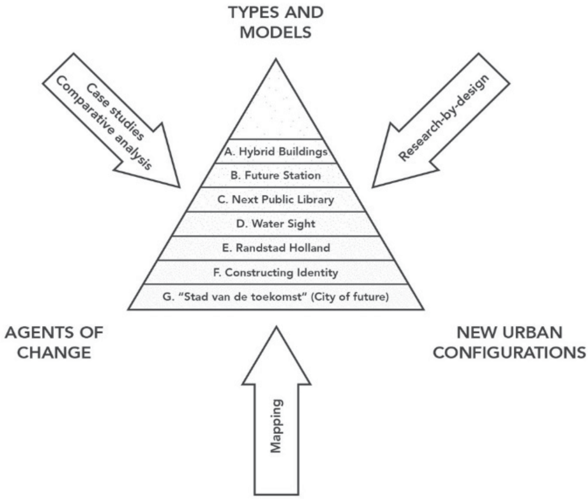
In fact, the public interior as well exterior public spaces of public buildings and urban blocks establish the physical manifestation of the public realm, and thus the object of study.

[1] In memory.

Approaches

The group utilises multiple research approaches to investigate public institutions and public buildings and their meaning for the city as:

1. Types and Models;
2. Agents of Change;
3. New Urban Configurations for the Contemporary European city.



To detect public buildings as 'agents of change', working through scales is essential. This reaches from the city as a whole to the urban block and to the individual building. The research includes A. the mapping of spatial transformations on the level of the building, the city, and the territory. It utilises B. comparative analyses of types and models and specific case studies, and C. Research-by-design conducted with (PhD) students, professional firms, municipalities and within (inter)national collaborations focuses on ongoing transformations and the development of new urban configurations for the future of the European city.

In this article we want to focus on these three main approaches within the Architecture & City program:

1. Comparative analysis and Case studies of Types and Models (Susanne Komossa, Nicola Marzot);

2. Mapping (Esther Gramsbergen, Otto Diesfeldt and Iskandar Pané);
3. Research-by-Design (Roberto Cavallo, Olindo Caso).

Current Research Projects

A. *Hybrid Building*, Nicola Marzot, Susanne Komossa;
B. *Role of Railroad Stations*, Roberto Cavallo, Manuela Triggianese;
C. *Next Public Library*, Olindo Caso;
D. *Water Sight*, Susanne Komossa, Inge Bobbink;
E. *OverHolland*, Esther Gramsbergen, Otto Diesfeldt, Iskandar Pané;
F. *Constructing Identity*, Sien van Dam;
G. *Stad van de toekomst* (*The city of the future*), Roberto Cavallo, Manuela Triggianese, Joran Kuijper.

The members of the group conduct the research in collaboration with members of other sections and departments of the Faculty of A+BE in Delft, professional architectural firms and bodies, and other faculties throughout Europe.

Case Study and Comparative Analysis of Types and Models: *The Legacy of Hybrids in Urban Design*

Prototype and paradigm

According to Linda Groat and David Wang

> *Case studies can be, like experiments, explanatory; however, they can also be descriptive or explanatory in purpose*[2] *(p.349). From specific cases, for example Jane Jacobs' analysis of New York, first the mechanisms and logics of one case are analysed to draw conclusions but also advice for more than one city. So, basically, they can be very specific, based on one case to come to more general conclusions or comparative to detect and identify certain issues and to understand how these are tackled in different circumstances.*

However, within our Architecture and City research we distinguish between prototype and paradigm in our research. Usually prototypes in architecture represent designs or design experiments of within the oeuvre of individual architects. These cannot be judged right away but it needs time to pass to explore their long-time performance (or failure). Paradigms are "proven" concepts that form part of the urban tissue in a given place and time, and which assume a conventional value. Also, they change in due course; for example, if we look upon the transformation of urban blocks in Europe. As such, all typo-morphological research belongs to the realm of paradigmatic cases i.e. of architectural types and urban models. Castex *et al*. define the architectural model as the actual architectural project, based on specific rules, concepts and techniques. Various projects may share the same rules and techniques resulting in distinguishable architectural and urban planning models[3] (pp.9–21).

Definition of the European Hybrid

Since the emergence of a renewed interest and discussion on urban form—prompted by the publication of Delirious New York and as a widespread phenomenon due to globalisation—hybrid, multi-functional buildings have been identified with Bigness, becoming synonymous of architecture competing with the city to take over its role. This ambition became even more evident by the increasing role played by infrastructural investments, caused by global financial capitalism. This phenomenon allowed to widen to the extreme global markets' reachability, both at material and immaterial level. The research Architecture and the City group on the argues that hybrids can relate to any transformation process of urban form, may it be big or small. Moreover, hybrid buildings challenge existing conventions and form the prerequisite for the elaboration of new ones.

The current environmental challenges are fundamental, especially regarding to reduction and abandoning of the use of fossil energy. Therefore, notwithstanding continuous migration to cities, the unlimited growth of cities' surface is no longer an option[4]. As a consequence, the urban transformation of former industrial areas, often located in the vicinity of city centres, densification of the existing urban tissue and the re-use of the current building stock will be some of the important future tasks of architects and urban planners. Due to climate change, future designs will also require innovative solutions for sustainable and integrated water and green systems. Changes in economy demand new ways to activate the city's public realm to provide space and realms for encounter for the new industries. Due to this recent crisis and economic recovery, we also witness a shift from "bigness" to "smallness", i.e., an integration of diverse functions of all scales in which traditional program divisions get more and more integrated. In Europe we usually study the so-called 'fabric hybrid' which is closely related to the un-going transformation of urban block[5] (p.8).

To make our point regarding the European city in the process of hybridisation and the forming of public realms, we selected a series of projects according to thematic recurrences. Re-assuming the tradition of the

Parisian Passage as the conventional output of a long-lasting manipulation of the urban block's inner core transformation that makes systematic use of breaking-thought streets, we analysed the Passage Coolsingel in Rotterdam. Focusing on the apartment complex "La Sportive" of Henri Sauvage in Paris as the result of the formal transformation of the block into a continuous envelope, which is in fact inside out, we discussed subsequently the design for the Markthal in Rotterdam. In addition, for example by reflecting on the bourgeois tradition of sheltering the courtyard of the urban block to establish market area, we developed a reflection on the Beurs van Oud in Rotterdam. All these 'cases' are selected, documented in a specific drawing template and thematically analysed in diagrams, text and by photographical/archival material. This analysis helps us to understand the inner logic of these paradigmatic examples[7] (p.209) and produce new knowledge for future projects on a small but also bigger scale. Or in other words, to understand the interrelationship between architectural typologies, models, and strategies.

Mapping: OverHolland, *Architectonische Studies voor de Hollandse Stad* (Architectural Studies for the Dutch City)

The group of Esther Gramsbergen is largely involved in morphological research that centres on cartographic methods for geographers, architects, and urban planners as a way of investigating the city and its territory. The so-called technical survey works with maps and data to identify the physical conditions, systems of buildings and water and green systems.

For the study of urbanisation from a physical and spatial perspective (historical) maps form among the most valuable sources. At the same time map making as a research activity is a powerful tool to analyse the urbanisation process. Especially when combined with statistical information cartography provides overview and insights that complement knowledge derived from the study of written sources. Analytic maps can throw light on the historical background of current design assignments and help to clarify them.

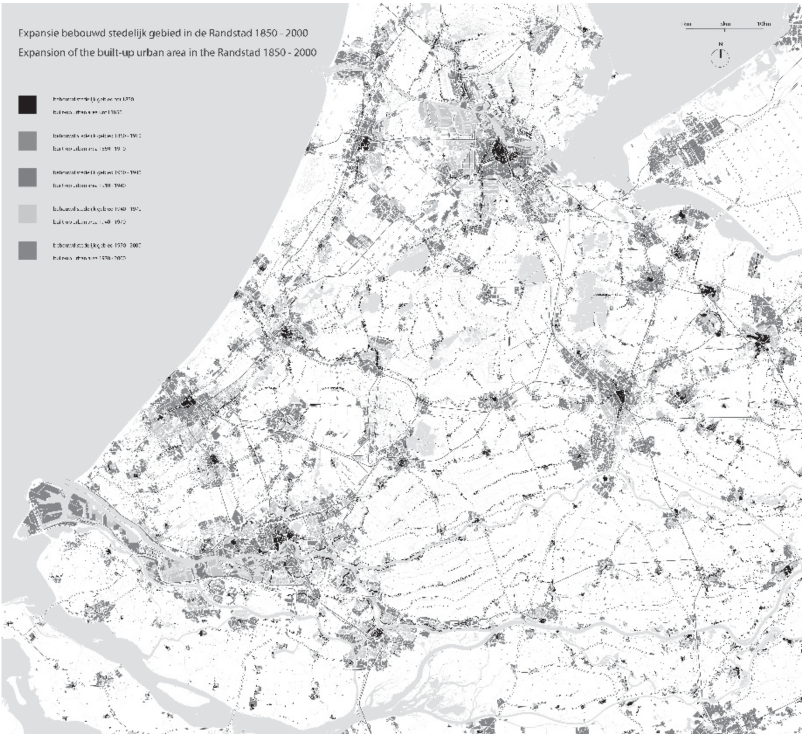


Figure 17.1

Chronological development map of the Randstad conurbation, 1850–2000. The growth map of the Randstad conurbation, 1850-2000 is a map of the Randstad region with the key infrastructural systems—waterways, railways and roads—and the build-up area as the substrate of five successive phases of urbanisation: 1850, 1910, 1940, 1970, and 2000. The five phases represent different morphological periods, urban fabric types that are still clearly distinguishable: the “canal city” (black) is typical of the period up to 1850; the “city of streets” for the period from 1850 to 1910; the ‘monumental city’ for the period from 1910 to 1940; the “open city of strips and bands” for the period from 1940 to 1970 and the “cluster city” for the period from 1970 to 2000 (from OverHolland[5] [p.38]).

Fifteen years ago, Henk Engel and Leen van Duin launched the research program Mapping Randstad Holland at the Faculty of Architecture at TU Delft. In this program PhD, students from different disciplinary backgrounds and staff members worked together to study and map the long-term spatial development of the Randstad.[8, 9, 10, 11] Over the years the program evolved;

it adapted to new technical possibilities of GIS and focused on new subthemes but kept true to the initial intentions and the well thought out systematic approach to mapping. This makes it possible to continue working on a growing body of knowledge of this specific region, and also to extent the methodology to other areas and merge in with the newly launched the "Architecture and the City" program. On a regular basis, the outcome of the research is published in OverHolland, a journal dedicated to architectural studies for Dutch cities.(2)

Figure 17.2

Development of the Randstad railway infrastructure in the nineteenth and twentieth centuries. The map shows the development of the network of railway infrastructure in the nineteenth and twentieth centuries, as compared with barge canals dating from the seventeenth and eighteenth centuries (from OverHolland[10, 11] [p.75]).

(2) The series is available in hard copy as well as online: https://journals.open.tudelft.nl/index.php/overholland.

Initial Intentions

From the beginning the typo-morphological studies of the Randstad region aimed to related to the issue of architectonic interventions. The interest for the architectonic intervention counted for historical as well as actual cases, with the final goal to understand how pre-urban landscape, cityscapes and architectural typology work together to form and reform the spatial identity of this area. This approach was tested in several Research-by-design projects, such as 5x5 *Projecten voor de Hollandse stad*, published in OverHolland[7] in 2008 and Renewing City Renewal. A Call for Strong Design [12]. These projects deliberately deal with a group of Randstad cities and the academic design briefs were formulated after a comparative map analysis of the cities involved.

A Systematic Approach to Mapping

The study area of the program is the Randstad conurbation, the most urbanised area of the Netherlands located in the western part of the country. It consists of a city system of nine historical towns, connected by a close-knit network of infrastructure and divided by a rural area (green heart). Next to chronological development maps and thematic maps covering the whole area, maps of the individual cities were produced, in order to compare them and related the changes on a regional scale with the transformations within the cities. The main instrument to relate the different scales and numeric data is a consequent use of specific timeframes or morphological periods: 1850, 1910, 1940, 1970, and 2000. These periods coincide with the dominance of certain specific urban configurations. The basic source for these series, that is elaborated in GIS, are the 1:50000 military topographical maps, which became available in the course of the 19th century and were consequently updated. For the detailed city maps additional sources, like historical city maps and cadastral maps, are used. The fixed periodisation, divided into steps of thirty years, makes it possible to produce informative diagrams on the expansion of municipal use of ground, based on both existing statistical information and calculations derived from the maps.

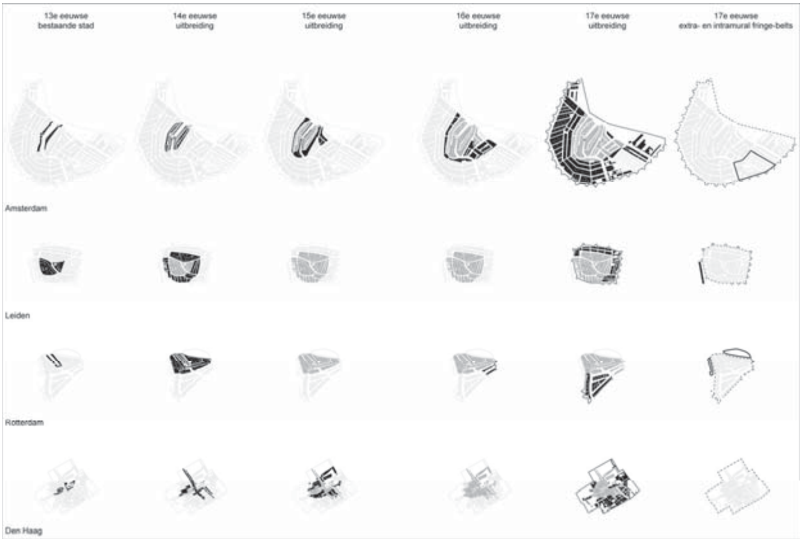


Figure 17.3

Historical city centres compared. Urban expansion up to the seventeenth century of the nine historical towns in the Randstad area. Built-up surface in the 13th century, 14th century city expansion, 15th century city expansion, 16th century city expansion. Most remarkable is the exceptional growth of Amsterdam in the 17th century (from E. Gramsbergen "De bruikbaarheid van de stadsmorfologische begrippen van M.R.G. Conzen in het onderzoek naar de Hollandse stad" in: Anne schram, Bernard Colenbrander, Kees Doevendans and Bruno de Meulder (eds.) (2015), Stadsperspectieven. Europese tradities in de stedenbouw. Nijmegen, NL: Vantilt. See also OverHolland[10, 11] (p 59)).

New Focus Points

Initially the basic map series was approached form a simple parameter: the expansion of the built-up city area. Later refinements were made by distinguishing between housing and working areas and putting more emphasis on factors and actors that catalyse urban change. This resulted in a series of six maps called Twelve centuries of spatial transformation in the Western Netherlands which especially focused on the role of the pre-urban landscape in the formation of the Randstad (OverHolland[10, 11]). Furthermore, public transport and public institutions were assigned as new focus points; fascinating themes that present themselves on the regional, city as well as on the architectural scale. As an example of the latter a comparative study into the changing city-university relationship in the Dutch towns is currently carried out (for the first results see OverHolland[18, 19]). To grasp more recent developments the original maps are updated to 2015.

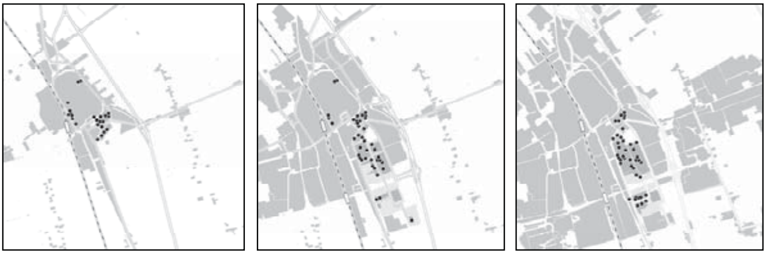


Figure 17.4

University facilities in the city of Delft: 1945, 1975, 2015. Delft is a relatively small university town in the southwestern part of the Randstad conurbation. The black dots show the distribution pattern of university facilities. The maps series is part of an ongoing study towards the university as a prominent agent of change in the contemporary city (from E. Gramsbergen "Universiteit en stadsontwikkeling tussen 1945–1975", in: Ab Flipse, Abel Streefland (eds.) (2020), De universitaire campus. Ruimtelijke transformaties van de Nederlandse universiteiten sedert 1945. Hilversum, NL: Uitgeverij Verloren. See also OverHolland[18, 19] [p.36]).

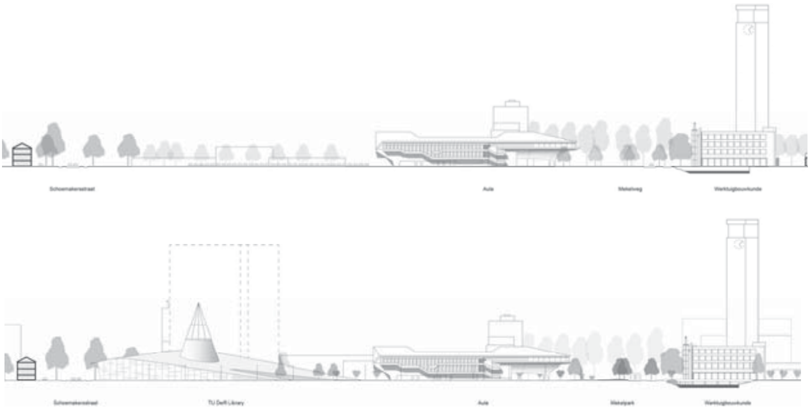


Figure 17.5

Section through the TU Delft Campus Area, at Christiaan Huygensweg from the north-west in 1975, above, compared to the situation in 2015, below (from OverHolland[18, 19] (pp.44–45).

Research-by-Design; *Stad van de Toekomst* (City of the Future)

Research by Design

Research by Design is nowadays widely considered as a key feature when talking about architectural research. Generating critical inquiry through design is something that can take place in practice as well as in academia. As design is essential in architecture,[13] inquiries based on design by both academics -educators and researcher- and professionals can contribute to the development of research in architecture and design.[14] The architectural design process constitutes the pathway via "which new insights, knowledge, practices of products come into being".[13] Following these premises, at the Department of Architecture of the Faculty A+BE, TU Delft, we have been working on the role of design in architectural research, having also the opportunity to be engaged with a number of remarkable experiences, in particular conferences and projects. The EAAE conferences Doctorates in Design and Architecture (1996), Research by Design (2000), The European City (2004) and The Urban Project (2008) have been milestones in developing scientific research based on design. Next to that, projects like 5x5 projects for the Dutch City (2008) and Renewal of Urban Renewal (2012) provided the very precious chance to interrelate Research by Design through research findings and education initiatives at the university with professional practice.

Thanks to the above-mentioned activities, we have been able to develop a methodological approach that we apply in research by design educational projects, like for instance the architectural design master courses of the Chair of Complex Projects. It offers assignments that typically address areas in transformation that are in need of grasping their possible futures[15] (pp.6–9): the American Midwest, the US-Mexico border, Cuba. In collaboration with the AMS Institute (Advanced Metropolitan Solutions https://www.ams-institute.org/) Complex Projects graduation students recently explored the future of Amsterdam in the year 2050. Results of this research-through-design study have been published in 2019.[16] The methodology adopted to unfold design assignments[17] includes a sequence of interconnected and cyclical steps that make use of abductive forms of reasoning[18, 19] informing conditional hypotheses. These steps construct the leading narrative and form the framework that unravels contextual complexity, contributing to envisioning and structuring the designs:[17]

1. "Journalistic" inquiry including a broad orientation on and separation (anatomy) of the context's layers in order to expose/reveal spatial, social, cultural, political, and economic conditions: mapping, physical models, interviews, site explorations, other sources;
2. Establish conditional relationships through the layers: speculative hypotheses based on "directed guesses". In this crucial phase findings are selected and organised with the aim to formulate plausible (= inference to the best explanation) hypotheses explicitly anchored into the inquired: questions, visualisation of "initial suspicions", collages;
3. Define a leading narrative that develops the initial 'suspicions' into a strategy, not avoiding contradictions and personal fascinations: urban diagrams, (annotated) maps;
4. Proposal of architectural topics informed by "state-of-the-art" typo-morphological explorations: concepts, program requirements, conditions for building and site, mass studies;
5. Design/testing of the proposals through iterative prototyping cycles: architectural interventions elaborated via drawings, models, details, visualisations and written reports.

While using this sequence of steps in an operative way, we constantly keep in mind that the design of complex assignments cannot be only inferred by relationships of causality proper of "traditional" science (deduction, induction) but also by relationships of conditionality proper of the investigation of possible futures[20]. This includes an iterative process of reflection and (design) decisions in which the made choices and the modalities of thought are documented and made explicit—in this case documented through the combined of collages, inquir,y and design books and/or physical models. Most of the educational projects we work on are strongly linked to current or future challenges in urban areas in The Netherlands and/or abroad, and very often related to research initiatives and/or projects in collaboration with other (built environment) disciplines and (external) partners.

Stad van de Toekomst/*City of the Future*

City of the Future (*Stad van de Toekomst*) is a large design research study. The central question of the study is: how to design and develop in an integrated way an inner-city transformation area into an attractive and future urban environment? This question is motivated by urgent social as well as local tasks in the urban areas, varying from housing demand, social inclusiveness, new economy, climate adaptation, and the like, considering the transitions in energy, mobility, circularity and digitisation. Based on future scenarios, the aim and intended results of this study are to obtain insights into the central and local questions in order to inform integral area development from systems and networks. In addition, also transitions to other spatial conditions are addressed. Such insights can have significance for the developments of a number of locations and contribute to the policy of local and central governments. Within this framework, the design research project *Stad van de Toekomst*/City of the Future was initiated by the BNA (The Royal Institute of Dutch Architects) and the TU Delft DIMI (Delft Deltas, Infrastructures & Mobility Initiatives), in collaboration with the Dutch Ministry of Infrastructure and Water Management and the Delta Metropolis Association. Other project partners are the Dutch Ministry of Internal Affairs and the municipalities of Amsterdam, Eindhoven, The Hague, Rotterdam and Utrecht. The five biggest cities of the Netherlands have to contend with a growing number of inhabitants. They all have to deal with compaction and expansion. Each of these five cities appointed a 1×1km transformation area to be analysed, researched and designed by two interdisciplinary teams of architects, urbanists, city planners, visionaries, engineers and sociologists—for the five cities there are in total ten multidisciplinary teams of practitioners fully involved with the project.

Moreover, the same assignments have been the base for two educational projects: a MSc2 studio with a multidisciplinary group of 30 students[21] and a Cross Domain Graduation Lab with 12 students from 4 different MSc tracks and 2 faculties. Both studios have been sharing the conviction that the city of the future is the city in which transformation and development go hand in hand with simultaneous focus on economy, ecology, and social dimension. Therefore, next to politics, practices and tools, aspirations of the city and planning approaches need to incorporate the common good, the citizens' perspective. While confronted with an ever-increasing complexity, there is a growing belief that networks of institutions, professionals, academics and citizens have to encounter in order to cope with the urban challenges of the future. Therefore, by adopting the above-mentioned methodological approach, both studios have been repeatedly engaging with the network of partners claiming interesting positions in terms of debate and mutual dynamics. Yet, by adopting the same theme and project locations, more than 50 students from TU Delft, IUAV Venice, Politecnico of Milan, University of Calabria and University of Rabat, have been working together in a thematic workshop that took place at the IUAV in Venice in September 2018. Last but not least, under the leading role of the TU Delft, all students, tutors and professionals from The Netherlands, along with the representatives from the BNA and the Dutch Ministry of Infrastructure and Water

Management, have been actively presenting and discussing the results of their work at a Biennale Session, part of the 16th International Architecture Biennale Exhibition in Venice.

Conclusions

The strength of this approach is constituted by the triangulation of academic debate, architectural education and professional practice at the same time. This means that the research program can serve these three pillars of architecture at the same time, allowing for cross-fertilisation from practice to education and architectural research. The integration of quantitative data with the analysis of architectural and urban form allows for a complex approach to today's issues of cities and public buildings.

References

1. Lofland, L.H. (1998), The public realm; Exploring the city's quintessential territory, New Brunsick, Aldine Transaction
2. Linda Groat, David Wang, Architectural Research Methods, New York, Wiley 2013
3. Johan de Walsche, Susanne Komossa, Prototypes and Paradigm, architectural research vis-à-vis Research by Design, DR_SOM, Delft, BK-Open, 2016
4. Edward Glaeser, Triumph of the City, How our greatest invention makes us richer, smarter, greener, healthier and happier, New York, Penguin, 2001
5. Joseph Fenton, Steven Holl, Hybrid Buildings, Pamphlet Architecture No. 11, New York/San Franzisco 1985, p.8. Fenton and Holl distinguish between Fabric Hybrids, Graft Hybrids and Monolith Hybrids
6. Job Floris, Susanne Komossa, Roberto Cavallo, Arie Lengkeek, Tekenboek stadsgebouwen; functiestapelingen, publieke binnenwerelden, in een blok. Rotterdam, AIR 2011
7. Susanne Komossa, The Dutch urban block and the public realm; Models, rules, ideals, Nijmegen, SUN, 2010
8. Cavallo, R. (2008). *Railways in the urban context: an architectural discourse* (diss. TU Delft)
9. Hurx, M. (2018). *Architect as profession. The origins of architectural practice in the Netherlands*. Turnhout, BE: Brepols Publisher (diss. 2010 TU Delft)

10. Brand, N. (2012). *De wortels van de Randstad. Overheidsinvloed en stedelijke hiërarchie in het westen van Nederland tussen 13de en 20ste eeuw* (diss. TU Delft)
11. Gramsbergen, E. (2014). *Kwartiermakers in Amsterdam. Stedelijke instellingen als aanjagers van de ruimtelijke ontwikkeling, 1580-1880*. Nijmegen, NL: Vantilt (diss. TU Delft)
12. Engel, H., Velzen, E. van, Wal, O. van der (2014). *Renewing city renewal. A call for strong design* (BK Books)
13. EAAE *Charter Architectural Research*: http://www.eaae.be/about/statutes-and-charter/eaae-charter-architectural-research/
14. H. Dunin-Woyseth, F. Nisson "Design Education, Practice and Research: on building a field of inquiry" in *Studies in Material Thinking* (2007) volume 11
15. K. Kaan "Complex Projects" in *Domus* (2015) volume 992
16. Kaan, K., Stancic, I., Triggianese, M., Smidihen, H., Zalingen, J. van, Oh Keng Yee, A. (eds.) (2019). Amsterdam 2050 Complex Projects. Delft: TU Delft Open. (https://books.bk.tudelft.nl/index.php/press/catalog/book/696
17. Caso, O., Verhoeven, W. (2018). *A Strategy for resilience. Alamar, Havana*. Paper presented at the 1st Bienial Research of Architecture VIBRArch, Valencia 18-19 October 2018. Publication forthcoming 2019
18. Dew, N. (2007). Abduction: a pre-condition for the intelligent design of strategy. *Journal of Business Strategy*, 28(4), 38-45. http://dx.doi.org/10.1108/02756660710760935
19. Hougaard, A.K. (2015). Architectural Practice in Research. Framed by Abduction. Ellefsen, K.O., Cleempoel, K. van, & Harder E. (Eds.), *Research by Design. EAAE 2015* (62-77). Diepenbeek, BE: EAAE
20. De Jong, T. (1992). *Kleine methodologie voor ontwerpend onderzoek.* Meppel, NL: Boom
21. Cavallo, R., Kuijper, J., Ardenne, M. Van, Heuvelmans, J. (eds.) (2018). *City of the Future. Stad van de Toekomst. MScII Design Studio Mobility & Public Space in the City of the Future*. Studio Report. Delft, NL: TUDelft

–PART II–

FORMAL PRODUCTION OF THE PROJECT AND DESIGN AUTOMATION

II.1

Syntax Developments

CHAPTER EIGHTEEN

SHAPES AND ATTRIBUTES

RUDI STOUFFS

Introduction

We consider shapes that are imbued with visual attributes, for instance, colour, thickness, texture, and labels, etc., and examine how such augmented shapes can be uniformly characterised so as to make themselves amenable to computation. For our purpose, a shape is defined as a finite arrangement of (rectilinear) spatial elements from points, line, plane, or volume segments, or higher dimensional hyperplane segments of limited but non-zero measurements. A shape is considered to be an element of an algebra U that is ordered by a part relation and closed under the operations of sum, product, and difference, as well as similarity transformations.

A shape can be augmented by distinguishing certain parts of the shape, which introduce additional spatial relations. Augmented shapes with attributes of a given type can be considered elements of an algebra V that has (about) the same property as U; it is ordered by a part relation and closed under the operations of sum, product, and difference, as well as similarity transformations.

The most common definition of a shape grammar[1] uses labelled points—that is, points with labels as attributes—as non-terminals. Stiny[2] proposes numeric weights as attributes to denote line thicknesses or surface tones. Knight[3, 4] considers a variety of qualitative aspects of design, such as colour, as shape attributes. Stiny[5] also proposes to augment a shape grammar with a description function in order to enable the construction of verbal descriptions of designs. Although most authors do not consider descriptions as attributes of shapes, Beirão[6] specifically considers descriptions as attributes of spatial objects. Other kinds of attributes, or even variations in the specification of a kind of attribute, can also be considered. For example, colours can be specified in different ways, as a three-dimensional RGB or

HSV (Hue, Saturation, Value) space, or in an enumerative way like Knight.[3,4] Labels may adhere to a strict textual format that allows for a different part relationship to be distinguished: for example, dates that can be chronologically ordered, or time intervals that may contain one another. Obviously, dates (and time intervals) may also be considered as numeric attributes, while visualised textually. For these reasons, a uniform characterisation of augmented shapes becomes important, such that new or different augmentations can be considered as part of augmented shape algebras.

In this paper, we review different shape attribute propositions from the shape grammar literature and characterise them uniformly. This uniform characterisation of augmented shapes is intended to assist in formalising new shape attribute propositions that may have been visually conceived. To demonstrate this ability, we explore a few different formalisations of coloured shapes within the uniform characterisation.

A Uniform Characterisation

Previous research[7] demonstrated how an algebra with carrier $\wp(P \times \wp(A))$ and signature, including sum, product, difference, and reduction, can be defined in terms of the (attribute) algebra with carrier $\wp(A)$ and signature including sum, product, difference, and reduction. As we are mainly interested in a uniform characterisation of shape attributes, we will limit P to denote the set of all points, while A may denote the set of all values of any single attribute type: e.g., labels, weights, colours, or descriptions. The *carrier* of the algebra denotes the set of elements of the algebra, and the *signature* of the algebra the operations of the algebra.

Let us represent a shape of points p with attribute *form a* by the pair (p, a), which we denote as a shape-attribute pair. This representation assumes that every point in p shares the same form of attribute values a, that is, every value in a is an attribute to every point in p. A general shape of points with attributes can then be represented as a set of shape-attribute pairs $\{(p_1, a_1), \ldots (p_n, a_n)\}$ with the shapes $p_1, \ldots, p_n$ entirely exclusive, that is, no two shapes p_i $(1 \leq i \leq n)$ and p_j $(1 \leq j \leq n \wedge i \neq j)$ share the same point. In addition, we require the attribute forms $a_1, \ldots, a_n$ to be distinct; otherwise, two pairs (p_i, a_i) and (p_j, a_j) with $i \neq j$ but $a_i = a_j$ can easily be replaced with a single pair $(p_i + p_j, a_i)$. Here, we adopt the general notation of sum, product, difference, and subshape on shapes, although these are equivalent to the set operations of union, intersection, difference, and subset on sets of points.

We can then express the behaviour of attribute shapes in terms of the behaviour of shapes. Firstly, we note that no form of attribute values can ever be associated with an empty shape. Therefore, we consider a function "e" to reduce any shape-attribute pair with a zero shape (an "empty" shape) to zero. For specific kinds of attributes, we may also not allow an attribute shape to have an empty form of attribute values. This is not necessarily the case for labels as attributes, as we could consider an empty set of (e.g., functional) labels to be a valid attribute form. However, when adopting labels in the case of layering shapes, e.g., in analogy to Photoshop layering, or filtering shapes in the case of say, medical tomography, we cannot accept an empty set of labels as an attribute form for a shape. The same restriction generally applies to weights as attributes. In order to distinguish both behaviours, we assume an additional value "nil", that is similar to zero, i.e., no value or an empty value, but distinguishes itself from zero in that a "nil" value is never allowed to persist as an attribute value, while a zero value may. Thus, we express the function "e" to reduce any shape-attribute pair with zero shape (an "empty" shape) or "nil" attribute to zero as follows:

$$\mathrm{e}(p, a) = 0 \qquad \text{if } p = 0 \text{ or } a = \text{nil}$$
$$(p, a) \qquad \text{otherwise} \tag{1}$$

In addition, we consider a function "m" to add a single shape-attribute pair (p, a) to a set PA of shape-attribute pairs, where p is known not to be part of any of the shapes in PA, though a may not be distinct from the attribute forms in PA. As any contribution to PA, and "m", may be 0, e.g., following the application of the function "e", we take the opportunity to remove any occurrence of 0 in PA.

$$\mathrm{m}((p, a), PA) = \quad PA \setminus \{0, (p', a)\} \cup \{(p + p', a)\} \qquad \text{if } \exists\, (p', a) \in PA$$
$$PA \setminus \{0\} \cup \{(p, a)\} \qquad \text{otherwise}$$
$$\mathrm{m}(0, PA) = \quad PA \setminus \{0\} \tag{2}$$

In order to simplify the behavioural expression for shapes of points with attributes, we will assume that each of the input shapes can be expressed as a single shape-attribute pair. Let x and y each represent a shape-attribute pair, that is, $(x : (p, a)), (y : (p', a')) \in \wp(P) \times \wp(A)$.

$$(x : (p, a)), (y : (p', a')) \in \wp(P) \times \wp(A) \Rightarrow$$
$$x + y : \mathrm{m}(\mathrm{e}(p - p', a), \mathrm{m}(\mathrm{e}(p \cdot p', a + a'), \{\mathrm{e}(p' - p, a')\}))$$
$$x - y : \mathrm{m}(\mathrm{e}(p - p', a), \{\mathrm{e}(p \cdot p', a - a')\})$$
$$x \cdot y : \mathrm{e}(p \cdot p', a \cdot a')$$
$$x \leq y \Leftrightarrow p \leq p' \wedge a \leq a' \tag{3}$$

Note that, while we assume that each of the input shapes can be expressed as a single shape-attribute pair, there is no such assumption about the result of the operations of sum, product, and difference on two single-pair shapes. In fact, the operation of sum may result in up to three shape-attribute pairs, that is, if neither a is a part of a', nor a' is a part of a, then the shapes $p - p'$, $p \cdot p'$ and $p' - p$ will each have a different associated attribute set and each of these three shapes may be non-empty. In the case of the operation of difference (of $(p, a) - (p', a')$), this reduces to up to two shape-attribute pairs as the shape $p' - p$ does not play a part in the result. In the case of the operation of product, only the shape $p \cdot p'$ contributes to the result. Finally, a shape-attribute pair is part of another shape-attribute pair only if the part-of relationship holds for the respective shapes and for the respective attribute forms. We note that this behavioural expression can be extended to general shapes of points with attributes, which are composed of multiple shape-attribute pairs, by comparing respective shape-attribute pairs and accumulating the results dependent on the operation under consideration.

An Exploration of Labels and Weights

Having established a uniform behavioural expression for the operations of sum, product, and difference and the subshape relationship for shapes of points with attributes, we now shift our focus onto a behavioural expression for different kinds of attributes. We have assumed a uniform characterisation for attributes of different kinds in terms of the operations of sum, product, and difference, as well as the part-of relationship. Let us explore these operations and relationships for various attributes.

A behavioural expression for forms of labels is easily expressed in terms of operations on sets of labels. Let x and y denote forms of labels, and X and Y the sets representing them, that is, $(x : X), (y : Y) \in \wp(L)$, with L the set of all labels. The empty set equates to the zero form.

$$
\begin{aligned}
&(x : X), (y : Y) \in \wp(L) \Rightarrow \\
&x + y : X \cup Y \\
&\qquad x - y : X \setminus Y \\
&\qquad x \cdot y : X \cap Y \\
&\qquad x \leq y \Leftrightarrow X \subseteq Y
\end{aligned}
\qquad (4)
$$

Note that Stiny's[5] descriptions share exactly the same behaviour with labels when used as shape attributes. Therefore, these descriptions will not be explored any further. On the other hand, when we consider the use of labels for layering shapes, e.g., in analogy to Photoshop layering or filtering shapes in the case of say, medical tomography, this behavioural expression must necessarily be adjusted. In this case, an empty set of labels equates to the "nil" form, rather than simply the zero form. We adopt the ternary conditional operator ("?:") to distinguish the case of an empty set of labels.

$$\begin{aligned}
&(x : X), (y : Y) \in \wp(L) \Rightarrow \\
&x + y : X \cup Y \\
&\qquad x - y : (X \subseteq Y \;?\; \text{nil} : X \setminus Y) \\
&\qquad x \cdot y : (\exists l \in X \wedge l \in Y ?\; X \cap Y : \text{nil}) \\
&\qquad x \leq y \Leftrightarrow X \subseteq Y
\end{aligned} \tag{5}$$

Next, we consider weights as attributes. Stiny[2] conceives a behaviour for weights (e.g., line thicknesses or surface tones) as is apparent from drawings on paper—a single line drawn multiple times, each time with a different thickness, appears as if it were drawn once with the largest thickness, even though it assumes the same line with other thicknesses. Thus, weights are never disjoint as any two weights always combine into a single value that is the maximum of both weights' values. Similarly, the common value of two weights is the minimum of both weights' values and Stiny[2] defines the difference of two weights in accordance with the arithmetic difference of their values, though the result can never be lower than zero. As a consequence, a form of weights is always represented as a singleton set. The behavioural expression for forms of weights can be written as follows. Note the use of "nil" instead of zero resulting from the subtraction of a bigger weight from a smaller weight in order to ensure that the resulting shape-attribute pair will be reduced to zero by the application of the function "e".

$$\begin{aligned}
&(x : \{w\}), (y : \{w'\}) \in \wp_1(\Re^+) \Rightarrow \\
&x + y : \{\max(w, w')\} \\
&\qquad x - y : (w > w' \;?\; \{w - w'\} : \text{nil}) \\
&\qquad x \cdot y : \{\min(w, w')\} \\
&\qquad x \leq y \Leftrightarrow w \leq w'
\end{aligned} \tag{6}$$

The exact same behaviour applies if we limit the weight values to within a specific range, e.g., real values between 0 and 1, or integer values between 0 and 255.

An Exploration of Colours and Materials

Having expressed the behaviours for labels and weights, let us explore additional behaviours drawing from, for example, Knight's[4] colour grammars. Knight[3, 4] considers varying behaviours for colours and materials. These apply to regions[4] or fields[3] and where these overlaps, rankings of colours or materials determine the resulting behaviour. For example, an "opaque" ranking implies that any coloured region that is added in a rule application covers any part of a coloured region already present in the design. That is, under an opaque ranking, the operation of sum on shapes with colours is not considered commutative: $x + y$ may be different from $y + x$. While Knight[3, 4] specifies what happens in the case of adding a coloured shape, she does not explicate any behaviour under product or difference, though she does present examples of rules and derivations from which it can be concluded that an exact colour match is required under the part-of relationship. Similarly, for the operations of product and difference, a coloured shape shares a part with another coloured shape only if both shapes share the same colour for this part.

Knight[4] generalises this "opaque" behaviour through rankings. When two overlapping shapes, each with a different colour, combine, the colours interact in accordance with their ranking. Either one colour is ranked higher and covers the other colour, or both colours rank equally and may be replaced by any other colour. Note that the ranking of two colours can be specified to be dependent on the ordering of the colours. This is the case for an "opaque" behaviour where any colour ranks higher than any other colour in that order if the first colour is being added to the second colour. If two overlapping shapes share the same colour, this colour can be replaced by another one, by virtue of the fact that both colours, being the same, rank equally. Knight[4] refers to the replacement of two colours by another one as the "blending" of the colours and offers an example with colours interpreted as materials, e.g., aluminium and wood. In line with this naming of colours, or materials, here, we consider colours as an enumeration accompanied by a matrix that specifies the ranking for each pair of enumerated values, or rather the value that results from combining both values. For example, Table 18.1 illustrates the ranking matrix for the opaque ranking considered above for two enumerated colours, "black" and "white" (see also[8]); Table 18.2 illustrates the ranking matrix for one of the materials ranking examples presented by Knight.[4] Note that Knight[4] only identifies the ranking in the case of equal materials, as other cases do not arise in her derivations. The matrix in Table 18.2 has been completed for unequal materials.

$x \setminus y$	black	white
black	*black*	*white*
white	*black*	*white*

Table 18.1

Ranking matrix for the opaque ranking of "black" and "white".

$x \setminus y$	aluminium	wood
aluminium	*aluminium*	*wood*
wood	*wood*	*aluminium*

Table 18.2

Ranking matrix example for material ranking.[4]

Denoting the ranking matrix as "xy[]", we can specify a generalised behaviour for colours specified as enumerated values with a ranking behaviour as follows. Note that similar to weights, colours are never disjoint and any two colours always combine under the operation of sum into a single colour, as specified by the ranking matrix. Therefore, a form of colours is also always represented as a singleton set. With respect to the operations of product and difference, and the part relationship, colours are always disjoint unless they are equal.

$$
\begin{aligned}
&(x : \{c\}), (y : \{c'\}) \in \wp_1(C) \Rightarrow \\
&x + y : \{\mathrm{xy}[c, c']\} \\
&\qquad x - y : (c = c' \ ?\ \mathrm{nil} : \{c\}) \\
&\qquad x \cdot y : (c = c' \ ?\ \{c\} : \mathrm{nil}) \\
&\qquad x \leq y \Leftrightarrow c = c'
\end{aligned}
\tag{7}
$$

We can also consider colour as defined within a three-dimensional RGB or HSV (Hue, Saturation, Value) space. As HSV is an alternative representation of the RGB colour model, colour values expressed in either space can easily be converted to colour values expressed in the alternative space. Therefore, we will reduce our investigation to the RGB colour space. More complex is the selection of a colour behaviour for the operations of sum, product. and difference, and the part-of relationship. Assuming we limit R, G, and B values to the range 0 to 255, adding two colours can never yield R, G, or B values higher than 255. Firstly, we can consider a behaviour similar to weights, where the combination under the sum of two component values yields the maximum of both values, the common value (under product) equals the minimum value of both component values, and the complement value (under difference) of one component value with respect to another is defined by the arithmetic difference, although it can never be smaller than zero.

$$
\begin{aligned}
&(x : \{r, g, b\}), (y : \{r', g', b'\}) \in R \times G \times B \Rightarrow \\
&x + y : \{\max(r, r'), \max(g, g'), \max(b, b')\} \\
&\qquad x - y : \{(r > r' \ ?\ r - r' : 0), (g > g' \ ?\ g - g' : 0), (b > b' \ ?\ b - b' : 0)\} \\
&\qquad x \cdot y : \{\min(r, r'), \min(g, g'), \min(b, b')\} \\
&\qquad x \leq y \Leftrightarrow r \leq r' \wedge g \leq g' \wedge b \leq b'
\end{aligned} \tag{8}
$$

However, we can as easily consider alternative behaviours: for example, where the combination under sum of two component values yields the average of both values. Such an approach could be argued for when mixing colours as paints. Mixing a lighter colour with a darker one will necessarily result in a colour that is darker than the lightest, yet lighter than the darkest. As we might be mainly interested in the behaviour of colours under sum, we could be forgiven for considering the exact same averaging behaviour for the operation of difference, while retaining the minimum value under the operation of product.

$$
\begin{aligned}
&(x : \{r, g, b\}), (y : \{r', g', b'\}) \in R \times G \times B \Rightarrow \\
&x + y : \{(r + r') / 2, (g + g') / 2, (b + b')/ 2\} \\
&\qquad x - y : \{(r + r') / 2, (g + g') / 2, (b + b')/ 2\} \\
&\qquad x \cdot y : \{\min(r, r'), \min(g, g'), \min(b, b')\} \\
&\qquad x \leq y \Leftrightarrow r \leq r' \wedge g \leq g' \wedge b \leq b'
\end{aligned} \tag{9}
$$

As another variant, we may consider adding an alpha value to a colour, specifying a transparency value for the colour when it is added to an existing colour. An alpha value can be any number between 0, full transparency, and 1, full opacity. Considering only a single component, the colour value resulting from the combination of a background and foreground colour with alpha value can be expressed as follows:

$$fg * \alpha + bg * (1 - \alpha) \tag{10}$$

Instead, we ignore the background colour and consider the sum of two colours, each with their respective alpha channel value, while considering the order in which the colours are combined, that is, which colour takes precedence over the other. Adding a second colour to an existing first colour, and interpreting the result as a third colour, we rewrite (10) as (i= r, g or b):

$$c_r.i * c_r.\alpha = c_2.i * c_2.\alpha + c_1.i * c_1.\alpha * (1 - c_2.\alpha) \quad (11)$$

Similarly, we derive the resulting alpha value as

$$c_r.\alpha = c_2.\alpha + c_1.\alpha * (1 - c_2.\alpha) \quad (12)$$

Note that when either the first colour is fully transparent (c1.α = 0) or the second colour is fully opaque (c2.α = 1), the resulting colour equals the second colour. Similarly, if the second colour is fully transparent (c2.α = 0), the resulting colour equals the first colour. Finally, if the first colour is fully opaque (c1.α = 1), then so is the resulting colour. Again, as we may be primarily interested in the behaviours of colours under alpha compositing, we may simply adopt the very same equations for difference and retain the minimum value under the operation of product. In order to simplify the behavioural expression, we consider a function "over" as follows:

$$\begin{aligned}
&\text{over}(\{r, g, b, \alpha\}, \{r', g', b', \alpha'\}) = \\
&\quad \{r', g', b', \alpha'\} \qquad \text{if } \alpha = 0 \text{ or } \alpha' = 1 \\
&\quad \{r, g, b, \alpha\} \qquad \text{if } \alpha' = 0 \\
&\quad \{r' * \alpha' + r * (1 - \alpha'), g' * \alpha' + g * (1 - \alpha'), \\
&b' * \alpha' + b * (1 - \alpha')', 1\} \qquad \text{if } \alpha = 1 \\
&\quad \{(r' * \alpha' + r * f) / \alpha'', (g' * \alpha' + g * f) \\
&/ \alpha'', (b' * \alpha' + b * f) / \alpha'', \alpha''\} \qquad \text{otherwise,} \\
&\qquad \text{where } f = \alpha * (1 - \alpha') \text{ and } \alpha'' = \alpha' + f
\end{aligned} \quad (13)$$

Thus:

$$\begin{aligned}
&(x : \{r, g, b, \alpha\}), (y : \{r', g', b', \alpha'\}) \in R \times G \times B \times A \Rightarrow \\
&x + y : \text{over}(x, y) \\
&\quad x - y : \text{over}(x, y) \\
&\quad x \cdot y : \{\min(r, r'), \min(g, g'), \min(b, b'), \min(\alpha, \alpha')\} \\
&\quad x \leq y \Leftrightarrow r \leq r' \wedge g \leq g' \wedge b \leq b' \wedge \alpha \leq \alpha'
\end{aligned} \quad (14)$$

Discussion

Considering a uniform characterisation of shapes imbued with visual attributes, we explored varying formalisations for these visual attributes with an emphasis on colours. This is far from an exhaustive enumeration of attribute formalisations. Stouffs[9] considers an alternative behaviour for weights where the operation of difference does not adhere to mathematical difference but, instead, acts in opposition to the sum operator: where adding a smaller value leaves the existing value unchanged, and subtracting a smaller value similarly leaves the existing value unchanged. While not a visual attribute, Knight[10] considers that a Boolean attribute is where the attribute value may be determined as the result of a function embedding an algorithm. Emphasising the fact that there is no “right” formalisation, our exploration is meant to demonstrate how researchers may conceive of a formalisation fitting the uniform characterisation of augmented shapes that suits a particular application. It is also meant to urge researchers to fully elaborate and express their formalisation, rather than only providing a rough conceptual description. In this way, not only can an implementation of the formalisation be conceived, but also other researchers may decide upon its usefulness for their own purpose or draw inspiration from it.

Research into shape grammars mainly follows two strands, which are sometimes intertwined. The first strand of research is on the representation and implementation of shape grammars, into which this paper falls. The second is the development of new shape grammars analysing a body of designs and/or supporting the design of instances of a particular type. While the latter may be conceived as pure application, in the absence of a general and broadly-adopted shape grammar interpreter, these developments of new shape grammars serve to feed the first strand of research with use cases from which to draw requirements and ideas for both theoretical developments and implementations, as well as methods to test such developments. For this reason, it is important that the development of new shape grammars is not limited to a conceptual ideation at too high a level of abstraction but, instead, that such developments are elaborated and explicated such that explicit requirements can be drawn from them. As shape grammars deal with different kinds and aspects of design, these may require different types of non-geometrical information to be incorporated and encoded. It is this process of encoding that this paper attempts to support, on the one hand, by offering a template for this encoding within a uniform characterisation of augmented shapes and, on the other, by demonstrating a few different formalisations of coloured shapes using this template.

Conclusions

We presented a uniform characterisation of the behaviour of shapes augmented with non-geometric attributes for the operations of sum, product, and difference and the subshape relationship. We demonstrated this uniform behavioural expression for shapes augmented, on the one hand, with labels and weights, which are two of the more common kinds of attributes in shape grammar development and, on the other, with colours, considering both a "ranking" of enumerative colours and behavioural expressions for colours defined within a three-dimensional RGB or HSV (Hue, Saturation, Value) space. Emphasising the fact that there is no "right" formalisation, this exploration is meant to demonstrate how interested parties may devise and formalise their own shape attribute propositions where necessary for the development of a particular shape grammar.

Acknowledgements

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References

1. Stiny, George. Introduction to shape and shape grammars. *Environment and Planning B: Planning and Design*, 7(3) (1980), 343–351.
2. Stiny, George. Weights. *Environment and Planning B: Planning and Design*, 19(4) (1992), 413–430.
3. Knight, Terry W. Color grammars: designing with lines and colors. *Environment and Planning B: Planning and Design*, 16(4) (1989), 417–449.
4. Knight, Terry W. Color grammars: the representation of form and color in design. *Leonardo*, 26(2) (1993), 117–124.
5. Stiny, George. A note on the description of designs. *Environment and Planning B: Planning and Design*, 8(3) (1981), 257–267.
6. Beirão, José Nuno. *CItyMaker: Designing Grammars for Urban Design*. PhD Thesis. Delft University of Technology, 2012.
7. Stouffs, Rudi. Implementation issues of parallel shape grammars. *Artificial Intelligence for Engineering Design, Analysis and Manufacturing* (in press).
8. Stouffs, Rudi. On shape grammars, color grammars and sortal grammars. In: Henri Achten, Jiri Pavlicek, Jaroslav Hulin, Dana Matejovska, eds. *Digital Physicality*, Vol. 1. Brussels: eCAADe, 2012. pp. 479–487.
9. Stouffs, Rudi. Constructing design representations using a sortal approach. *Advanced Engineering Informatics*, 22 (2008), 71–89.
10. Knight, Terry. Computing with emergence. *Environment and Planning B: Planning and Design*, 30(1) (2003), 125–155.

II.2

Generative Grammars

CHAPTER NINETEEN

GENERATING FORMS VIA INFORMED MOTION: A FLIGHT INSPIRED METHOD BASED ON WIND AND TOPOGRAPHY DATA

DEMIRCAN TAŞ, OSMAN SUMER

Introduction

The use of computational techniques has shifted the paradigm of architectural design practice. Oxman[1] suggests that dynamic, responsive space and form, producing new classes of designs have been made possible by digital technologies. Design is no longer constrained to discrete shapes in the traditional sense. Design experimentation is not reliant on paper-based sketching, thanks to the exploitation of generative-based processes of transformation. Design context of the modernist approach may be iconic, stylistic, or configurative while digital design context is a "per-formative shaping force acting upon shape, structure and material".

According to Carrara,[2] architectural design processes can be defined in three steps. The definition of goals, generation of various solutions, and evaluation of the satisfaction of said goals provided by the suggested solution. Goals are generated through analytical and deductive means are transformed into structured sets of requirements. Created through intuitive and inductive processes, solutions are invented or adapted to contain performance characteristics that achieve the requirements and other desired attributes. While the solutions are evaluated, requirements are also modified in order to accommodate emerging opportunities as well as to overcome unconformable conflicts.

Problem Definition

Generative systems have been utilised for various phases of design, creating form via shape grammars, cellular automata, genetic algorithms, l-systems and swarm intelligence.[3]

The subject of this paper is design work carried out in order to create a design algorithm based on generative systems, viable for the rapid generation of a large body of solutions to design requirements of complex nature. The intention in creating such algorithms was to create an explicit and responsive workflow that generates form, based on contextual information and fluent user input of both digital and analog nature.

Our work aims to combine digital algorithms with material design models and collected data. This paper aims to clarify our processes and trials, resulting in the creation of a swarm intelligence (SI) based generative design algorithm as part of a team effort within the Generative Systems in Architectural Design class within our master's studies while trying to make the *relentless boundary between the digital and the material*[4] more permeable.

Aims and Objectives

The main objective of our work is to reduce the creative gap between physical models and digital systems. Our aim is the creation of adaptive algorithms that generate initial design shapes based on contextual data and analog models. Arbitrary wind speed and direction data were utilised within our trials, yet data of different nature and origin can be fed into the system in order to create complex, contextual forms for differing environments and design goals. Another aim of this study is to create a coordinated[5] design algorithm where results are based purely on the input of design and field data. Ambiguity and experimentation are based on user interactions, not random variables.

	A	B	C	D	E
1	Station	UTMX	UTMY	Direction	Speed
2	ST1	615380	9531496	22.5	16
3	ST2	616004	9533157	45	14
4	ST3	617630	9533808	90	12
5	ST4	619191	9532326	135	12
6	ST5	621295	9530663	112.5	7
7	ST6	622303	9533906	180	6
8	ST7	616992	9532169	10.5	18

Table 19.1

Conversion of spreadsheet data to 2D spatial coordinates.

Results of our trials will be compared with regards to the presence of emergence and self-organisation. De Wolf and Holvoet[6] define emergence as follows:

> *A system exhibits emergence when there are coherent emergents at the macro-level that dynamically arise from the interactions between the parts at the micro-level. Such emergents are novel w.r.t. the individual parts of the system.*

Self-organisation is defined by the same authors as:

> *a dynamical and adaptive process where systems acquire and maintain structure themselves, without external control.*

Another aim of our work is to bridge the gap between the analogue material, created via human input—or taken from nature—and the digital, especially the generative tools provided via digital computation as a possible way to create and design with the digital, as opposed to the current paradigm of merely producing through the digital.[7]

Methods

Our workflow is based on the scanning of a physical model via photogrammetry tools and enriching the acquired 3D model with spatial data through raster maps. The acquired landscape model is combined with the raster data by the use of UV mapping techniques. Generative algorithms were tested on the informed digital model along the course of three trials, providing us with a volume of forms that can be utilised for design.

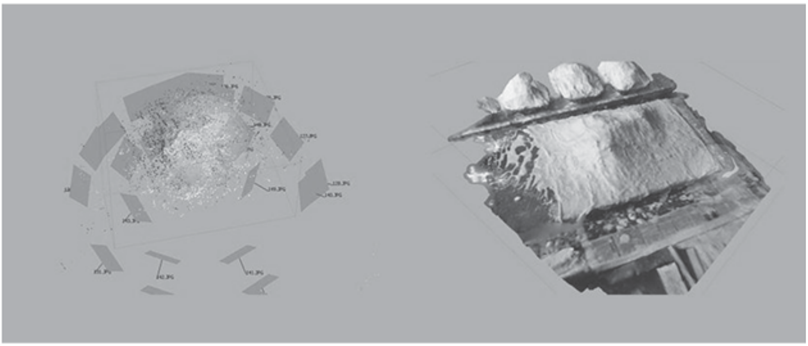


Figure 19.1

Digital landscape model acquired via photogrammetry

For the creation of the physical model, pieces of crumpled paper were used to generate underlying forms with the inherent characteristics of the material combination. Wet, plaster-soaked bandages were placed on the paper base and left to dry. Multiple such topographies were constructed in order to test the adaptive nature of our system.

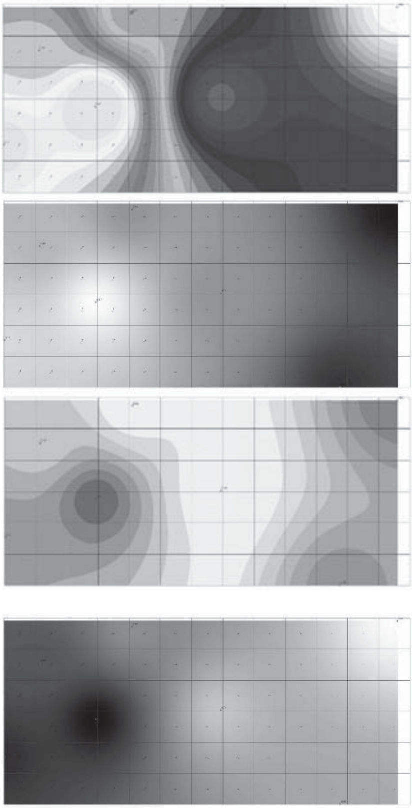


Figure 19.2

Raster maps acquired by interpolation.

An off-the-shelf approach was adopted for most of the digital methods. Agisoft Photoscan software was used for obtaining digital models from the topographic models by digital photography. Animation software from Autodesk was utilised to retopologize the Triangulated Irregular Mesh (TIN) geometry to quad based representations in order to obtain higher quality surfaces for digital calculations.

The approach was tested on a fibre and moulding plaster composite, handmade landscape model which was digitised by means of photogrammetry. Arbitrary numbers were constructed as a simple database in spreadsheet software. Raster maps of continuous and differentiable nature were necessary for the application of the necessary tools on the digital surface. Data was converted into digital material of the necessary attributes by the use of inverse distance weighting algorithm within ArcGIS[8]. The interpolated raster data was mapped to the scanned surface via the use of UV[9] mapping techniques within Maya. Algorithms were iterated on the terrain geometry, connected to the spatial data within the animation software.

Responsive geometries were created with the use of digital animation techniques. These forms were instantiated on the landscape based on different methods with the aim of combining their adaptive nature with the underlying landscape.

Initially, multiple models of avian inspired forms were digitally modelled as polygonal forms. We have combined these models with a morphing tool, where one shape can be animated to transform into a different shape with similar polygonal topology.

Our second modelling approach is similar to long exposure photography[10] where the position of an object on different times is captured on a single image. Different simple geometries were animated based on wing motion of birds via an Inverse Kinematics (IK) algorithm[11]. Resulting positions within a certain timeline were combined in order to create static forms. Forms created through this method resemble the aesthetic characteristics of avian creatures.

Morphing and IK algorithms were utilised for different trials. Pieces were instantiated on a surface, driving the morph animation and orientation of each part via the field data. Motion of individual parts (via IK), resulting in the animation of the whole was instantialised for each frame, in order to acquire dynamic forms.

Trial I

Our first trial was based on morphing shapes. Multiple starting positions were created based on avian forms and a morph algorithm was utilised in order to interpolate any number of hybrid shapes.

The resulting shapes were placed on the terrain via a parametric scattering algorithm in a grid-like pattern. Affine transforms of each instance were exposed in order to match such attributes to data. Additionally, the morph animation was limited within certain frames and frame number attribute was also exposed as an input channel.

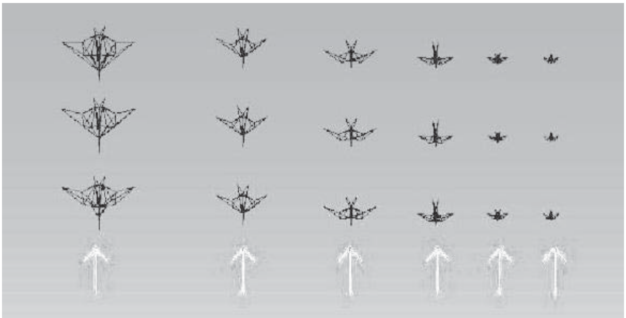


Figure 19.3

Multiple forms with similar topologies defined as morph targets.

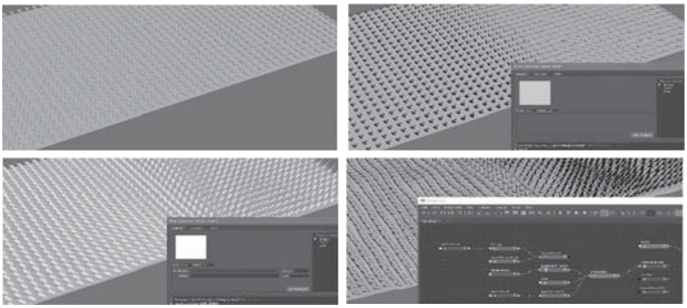


Figure 19.4

Progression of shapes, from regular arraying without data input through affine rotation, scale and frame connections.

The linear grayscale raster images were used as input in Maya to provide local values to be input for each model instance. This resulted in each model acquiring its frame number from the wind speed, and orientation from the wind direction values. While initially regular and static, manipulation of local pivot positions caused dynamic patterns to emerge.

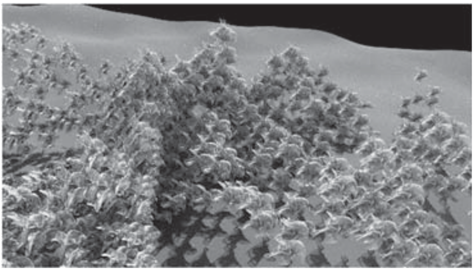


Figure 19.5

Emergence obtained via pivot point manipulation.

Trial II

In addition to morph animation, we searched different results through an IK based method. A linear set of joints were created to be combined with an end locator (IK handle). By constraining the end locator to simple curve geometries, complex avian-inspired forms emerged from simple sweeping motions. Rather than recursively scattering the results as static models, motions were preserved and combined with an additional layer of animation. This resulted in more dynamic shapes that also involved characteristics of the given motion. Combination of different animations provides freedom when creating forms, even making it possible to draw with the top layer animation.

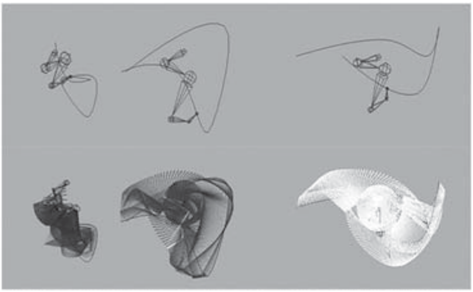


Figure 19.6

Emergent forms acquired via “long exposure” of sub-shapes connected to IK rigs.

Multiple shapes can be combined in an IK system where their spatial relationships can be animated via affine transforms, informed by the IK effector. The total animated group can itself be constrained to animation paths, creating adaptive forms via the snapshot algorithm.

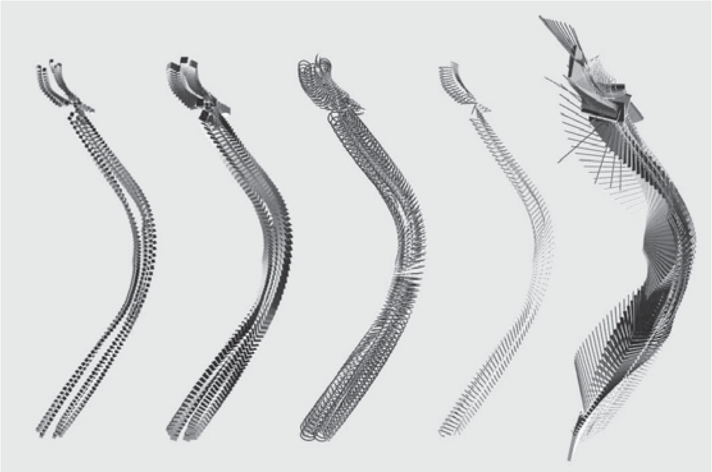


Figure 19.7

IK system combined with top level sweep animation.

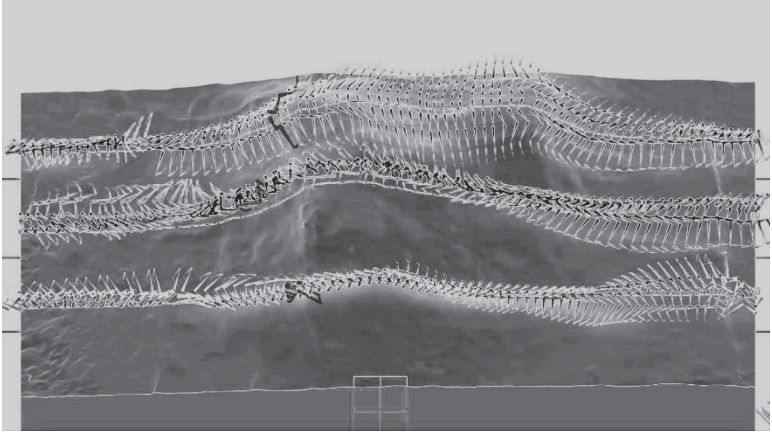


Figure 19.8

Sweep animation applied to curves projected onto landscape geometry.

Trial III

In the third trial, swarm intelligence (SI) was investigated through the flight node of the MASH plug-in within Maya. The flight node is based on a particle system based on three basic rules of swarm behaviour: collision avoidance, velocity matching and flock centring.[12] Additionally, attractors or detractors can be placed and weighted in order to shift the position for flock centring, practically attracting or scaring the particles. An attractor was animated, based on the raster data, future work may include a detractor. The landscape either literal, or as a fitness landscape is used as the environment for problem solving. Our examples were generated on a scanned 3d landscape model. Similar to the dog and frisbee metaphor put forward by Lynn, where a solution is chased in the fitness landscape by an agent.[13] In our system however, the intuition of a metaphorical dog is replaced by the collective intelligence of the swarm and the fitness landscape is replaced by a virtual one.

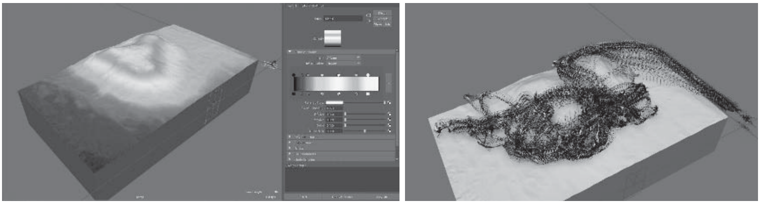


Figure 19.9

Adaptive forms generated via long exposure of the swarm animation on the informed landscape model.

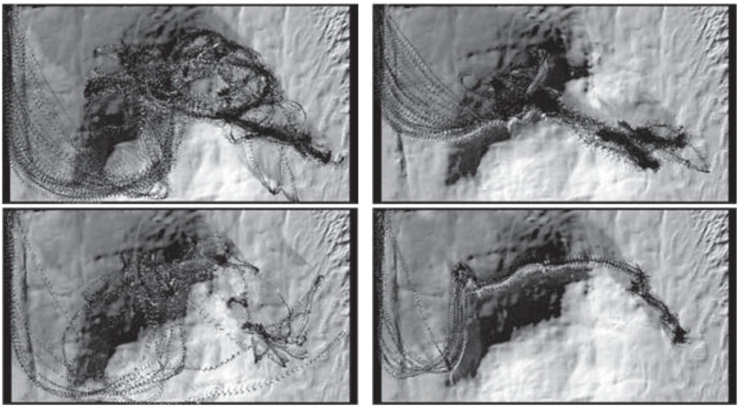


Figure 19.10

Varying results of the swarm test.

Agents were constrained to the terrain geometry, while the attractor was positioned below. This in effect created a situation where climbing was not favourable due to increased distance from the attractor. Multiple simulations were created with variations on the attractor animation and SI parameters.

Results and Discussion

Through the application of our trials, a form creation algorithm was created. Utilising basic animation techniques and simple models, forms of a more complex nature can rapidly be generated. The results are based on the underlying landscape and the data field as well as user input. Manipulation of different parameters creates a situation where the designer has ample control on the results, similar in concept to the sweeping motions of a watercolour brush. The forms, while following the user motion, are shaped by the underlying data. By the application of these algorithms on scanned geometry, user input and collected data, complex, informed and adaptive forms can be generated.

The results are achieved through multi-layered animations of a set number of agents, each animated by the motion of their parts as well as on the landscape while collectively seeking the ideal path to the attractor, creating forms, adaptive to the terrain as well as the path of the attractor.

Solid models are acquired through the process, displaying characteristics of the embedded data fields, the scanned physical model and the user input through attractors. Resulting shapes although complex, include no ambiguity, similar results are achieved when the simulation is run with the same user input and data, unless parameters are intentionally randomised. With regards to the definitions made by De Wolf and Holvoet (2004), trial I can be considered as a simple parametric system that involves neither emergence nor self-organisation since the system is always at an ordered state. In a case where object pivots were offset; however, the system did display emergent behaviour which can be the subject of a further study.

Trial II contains cues of emergence, since resulting shapes do contain a "gestalt", not visible within the individual inputs. The system, with a static level of order does not exhibit self-organisational behaviour. It is when both the landscape data, IK animation and SI are combined in trial III that the system displays self-organisation as well as emergence. Despite containing no ambiguity, the system produces resulting forms that are irreducible. When agents are released upon the virtual landscape, the initial state of chaos evolves into higher order without external organisational input.

Our methods can be utilised for early design process of architectural design projects where complex field data is available or can be generated/ mined by the designer. On a different level, these algorithms can be used on analogue concept models in order to derive computation-based results which can also be used for further stages of design. While our current work displays three dimensional forms of bird-like nature shaped by the wind data, it is possible to replace both the data input, and animation characteristics in order to generate designs of differing nature and varying levels of abstraction. Yet such possibilities were out of the timetable of our project schedule; it is our aim to introduce more variety in the future.

The main objective of our study was to bridge the design gap between material and digital processes. This condition is partially satisfied. While the process is fluent in carrying the form of the analogue model to the virtual space, most design input is through animating attractors digitally, and adjusting floating parameters. Future work may see these inputs connected to more immersive interfaces, in order to keep the process more fluent for a broader user base.

The main output of the work in its current form is visual, applied on the physical model via projection mapping. While such visual output is fast and suitable for quick design feedback, there may be potential for cases where the output can actually reshape the physical model through rapid additive or subtractive manufacturing processes.

Conclusions

Through this study, we aimed at combining physical models with generative systems in order to create processes for early design exploration. Forms are to be generated through the use of data fields, scanned models or actual terrain and user input of analog and parametric nature. Ambiguity is limited to user preference and not integral to the processes.

Based on a series of three trials, we have created a set of algorithms for the generation of informed geometries. The shaping factors can be as simple as curves, drawn in 2d space to multi-dimensional field data, utilised as rasters. Resulting shapes are complex, yet consistent and the system developed to generate them can be self-organising, emergent or both.

Our work focuses on creating a fluent design process where the transition between the physical and the digital is as smooth as possible. Further work can be carried out in order to create a more physical interface for input from the designer while also utilising the systems for digital fabrication techniques in order to reshape the original physical material via the output.

Results of our processes resemble the visual characteristics of avian creatures, combined with the wind field data, yet our system is open ended in nature where both the avian IK animation and the field data can be replaced with an endless range of material for differing contexts. We hope to test such possibilities in the future.

References

1. Oxman, Rivka. *Novel Concepts in Digital Design.* In N. Gu& X. Wang (eds.), Computational Design Methods and Technologies: Applications in CAD, CAM and CAE Education. Pennysilvania: Hershey Press, 2012. pp. 18-33.
2. Carrara, Gianfranco. KALAY, Yehuda. NOVEMBRI, Gabriele. *Knowledge-Based Computational Support for Architectural Design: Automation in Construction.* Rio de Janeiro:Elsevier, 1994. pp. 157-175.
3. Singh, Vishal. GU, Ning. *Towards an Integrated Generative Design Framework.* Design Studies vol.33, i2. Design Studies, 2011

4. Gun, Onur Yüce. *Computing with Watercolor Shapes: Developing and Analyzing Visual Styles,* In Gülen Çagdas, G. Özkar, M. Gül, L. and Gürer, E. (eds.) Future Trajectories of Computation in Design [17th International Conference, CAAD Futures 2017, Proceedings. Singapore: Springer, 2017. pp. 252-269.
5. Theraulaz, G. Bonabeau, E. *Modelling the Collective Building of Complex Architectures in Social Insects with Lattice Swarms* In Journal of Theoretical Biology, 177 (4), 1995. pp. 381-400.
6. De Wolf, Tom. Holvoet, Tom. *Emergence versus Self-Organization: Different Concepts but Promising When Combined.* Lecture Notes in Computer Science, vol 3453. Berlin: Springer, 2005. pp. 1-15.
7. Pinochet, Diego. *Discrete Heuristics: Digital Design and Fabrication through Shapes and Material Computation*. In Gülen Çagdas, G. Özkar, M. Gül, L. and Gürer, E. (eds.) Future Trajectories of Computation in Design (17th International Conference, CAAD Futures 2017, Proceedings). Singapore: Springer, 2017. pp. 306-326.
8. 8., Donald. *A Two-Dimensional Interpolation Function for Irregularly-Spaced Data.* In Proceeding ACM '68 Proceedings of the 1968 23rd ACM national conference. New York: ACM, 1968. pp. 517-524.
9. Palamar, Todd. *Texture Coordinates.*In Mastering Autodesk Maya. Chapter 9. Indianapolis: Wiley, 2014. pp. 399-420.10.
10. Tang, Ming. *Animation as a Modeling Tool.* In Parametric Building Design Using Autodesk Maya. Chapter 7. New York: Routledge, 2014. pp. 139.
11. Palamar, Todd. *Rigging and Muscle Systems.*In Mastering Autodesk Maya. Chapter 9. Indianapolis: Wiley, 2014. pp.207-236.
12. Reynolds, Craig W. *Flocks, Herds and Schools: A Distributed Behavioral Model.* In SIGGRAPH '87 Proceedings of the 14th annual conference on Computer graphics and interactive techniques. New York: ACM, 1987. pp. 25-34.
13. Lynn, Greg. *Animate Form New York: Princeton Architectural Press, 1999. pp. 9-41.*

CHAPTER TWENTY

GENERATIVE BIOMORPHISM

RICARDO MASSENA GAGO

Introduction

The morphological gap between human and biological structures comes from a design problem. Biological structures coexist in the surroundings by coherence. The coherence allows their interaction and harmonious socialisation. Makes them work as a whole. Human structures do not follow this path. The solutions proposed do not socialise for a mutual benefit. Why? They do not share the same “morphological language” which makes them repulsive.

Biological structures are the highest reference in the ecological field. According to Christopher Alexander,[1, 2] if human structures aim to reach such level, they should follow the same design process of the biological ones. However, this goal is revealed to be utopian at present. The complexity level revealed by these objects is enormous. Its decoding requires a collaborative effort between several scientific fields. The main complexity of biological structures resides in the relation between functionality and metabolism. However, regardless of their diversified processes they all follow a common geometrical pattern. It means that they share a geometrical identity that can be quantified regardless their function. This research aims to achieve a higher morphologic coherence between human and biological structures.

The goal is the development of structures of architectural purpose following the generative design process that characterises the biological identity. For that purpose, the research focuses on the following aspects: 1) identify and define the geometric pattern that characterises the identity of the biological morphology and 2) develop a design tool of geometrical essence able to decode and implement the pattern in human structures.

To transfer and implement the biological identity into human structures the drawing tool requires the following topics: 1) the selection of a generative drawing tool (shape grammars) able to explore the geometrical pattern through a shape diversity perspective and 2) the definition of a geometrical inventory described by rules (geometric and algebraic language). This research emerges in the ecological design field as a design strategy that seeks to emphasise the idea that the ecological quality requires a specific geometric pattern allowing its experimentation and understanding through a design tool.

Background

The attempts to break the morphological divergence between human and biological structures have already led to the emergence of several design strategies. In this field strategies as biomimetics and digital morphogenesis stands out.

Biomimetics is a design strategy that tries to use the biological knowledge in human profit. This profit could be by human need or by human benefit. The biological structures reveal the best-known relation between shape configuration and function. So, this strategy tries to mimic the shape/process configuration in order to optimise a function for a human need. It means that its ecologic purpose focuses mainly at the object level by using a direct copy approach of a particular configuration[3, 4]. In turn, digital morphogenesis changes the ethic of the bio inspired design by highlight the generation process rather than object replication. The design process contemplates the union of the concepts of emergency[5], self-organisation[6] and matter (natural and synthetic). The generative process is based on algorithms (patterns and rules). They are introduced in a computational process with the aim of generating shapes that provide maximum optimisation of the material resources, taking into account functional, material and environmental constrains[7, 8]. So, this strategy seeks to counteract the hegemony of the pre-idealised shape through the implementation of a design logic where the designer is left out from the generative decisions. Recently, the digital morphogenetic concept has evolved and started to explore the synthetic biology in its design process. The addition of this concept had an important role in accepting the growth as an important factor in the generation process of biological structures[9]. What are the main differences between these design strategies?

Biomimetics is not concerned with the generation process, but in take advantage of the products morphology in order to optimise human design problems through a biological perspective. So, it reveals to be a static design process based on a simple goal. In turn, digital morphogenesis does not dissociate functionality from a design process. It is based on shape diversity for adaptation purposes. It reveals to be a dynamic process based on change and evolution. The digital morphogenesis reveals a design process more similar to the biological ones. The drawing tool proposed by this research will follow its principles.

Biological Identity

Design Requirements

The biological structures are perfectly recognisable in the environment regardless their shapes. This identification is only possible because their morphology informs that they have this quality. It means that the phenomenon of life imposes a signature in its structures, i.e., they reveal an identity.

According to Celso Vieira,[10] the identity is a quality that lies in the process and not in the object. The object only shows its signature. In morphological terms, it means that the identity resides in the shape geometry. However, the geometry by itself is not enough to generate identity. It also requires an organisational pattern flexible to change in order to allow shape diversity. In biological structures this organisation is imposed by growth mechanisms and based in a design process that follows generative principles[2]. In geometrical terms, the implementation of the biological identity in human structures demands at least three design requirements a generative design process, growth mechanisms and a geometrical pattern.

Generative Process of Biological Structures

Why bio inspired structures should follow a generative design process? Biological structures have the ability of change without compromising their identity. The objects are constantly changing, but their morphological signature is static. However, the change can occur in two different design perspectives _ by similarity or by dissimilarity. Two biological structures of the same species are never equal, but rather similar. To achieve identical structures the generation process should be repeated. However, to achieve similarity the process sequence should reveal little changes. In turn, different species without any genetic relation reveal a different morphological configuration. Nevertheless, they continue to be recognised as biological. So, this morphological dissimilarity by the maintenance of the identity requires a common design process with great changes in the generative sequence. Although to maintain the identity the process should share the same inventory. What generates diversity is how the inventory is sequenced. How can it be achieved? On the one hand by switching rules in the generation cadence. On the other hand, by increasing/decreasing the repetition sequence of one or more rules or without any sequential repetition at all. So, their design process follows a generative process. It is the process that allows achieving copy by "error" (similarity).

The Growth Mechanisms of Biological Structures

What is the role of growth in the generation process? At the geometrical level it imposes a structural organisation[11]. Growth requires a metabolic process of replication that increases the mass of the structures by adding new elements generated by the existing ones. It imposes an expansion process based on elements dependence, which means that all the elements are related to each other and arranged for a common purpose. So, it is an expansion process based on recursion. However, the expansion is not random. It follows a pattern. Growth expands through a centroidal configuration (wave or spiral) characterised by expansion levels which tend to increase their proportion as they move away from the origin. So, it is a process that follows a gradient pattern characterised by the generation of a force field that highlights its origin (the centre). The result is the emergence of structures with a strong cohesion level that seems almost unbreakable.

The Geometry of the Biological Pattern

The geometry in biological structures emerges in two distinct levels: in the identity level and in the functional level. The identity level is what makes biological structures recognisable regardless their shapes. The identity requires a process consisting of an inventory and a generative tool to combine them (growth). The functional level uses the geometrical principles of the identity level and it is controlled by an unknown cognitive entity. Taking into account the local constrains (materials and environment) and the functional goal, this entity develops a metabolic process that designs the shape in order to its survival.

Due to the fact that the biological identity can be recognised regardless its function, it means that it can be studied separately from its metabolic process. What geometry characterises it? The growth process of biological structures results from a reproduction process of elements addition that should follow a particular organisation. However, the relation between both is not random. It should follow geometrical and proportional requirements. In terms of geometrical qualities, the elements should be formed by shapes of triangular derivation (polygons) being the hexagon the referential shape. The elements shapes should also reveal local symmetries. Their arrangement in space should be made by simple aggregation overlapping the shapes boundaries and should follow an expansive organisation using spiral or wave patterns. As regards proportional requirements, the order of magnitude between adjacent elements must follow the harmonious values of the golden ratio. The same order of values should control the expansive levels (growth) of the structural organisation. Following these requirements, the elements distribution must generate shapes characterised by irregular curved boundaries (concave and convex surfaces) (Figure 20.1).

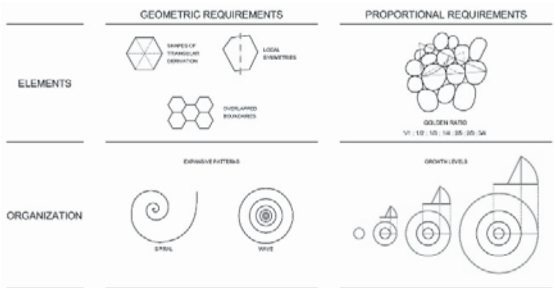


Figure 20.1

The geometrical and proportional requirements of the biological pattern.

Design Process

The generation of human structures that follows the biological geometric pattern requires a generative drawing tool able to decode it and apply it in new morphological configurations. For that purpose, the algebraic and geometrical language of shape grammars is used. Shapes grammars is a generative drawing tool that decodes geometrical pattern in rules (inventory) in order to generate shape diversity with the same geometrical identity. It is a drawing tool based on shape transformations through a step-by-step process, which allows the generation of new elements from others that already exist[12]. This transformation process is made by a process of shape replacement that uses Boolean and Euclidean algebras through a parametric approach. The rules cadence should follow a repetitive and/or alternated pattern. The rules sequences define the shape code and its unique configuration within a specific morphological identity.

Inventory Definition

The inventory of the drawing tool is composed by rules that decode the geometrical pattern of a particular morphological identity. In this research, the rules decode the following geometrical qualities of the biological morphology: expansive patterns (wave and spiral configurations), structural shapes (shapes of triangular derivation), a proportion pattern (the magnitude values for shapes, expansion process and structural elements), symmetry patterns (bilateral and rotational symmetry) and boundaries configurations (concave and convex surfaces).

Generation Process

The shape generation requires a generative and parametric design divided in two phases. The first phase defines the shape and its materialisation. For that purpose, two types of rules are used: hidden rules and materialisation rules. As regards second phase, it defines the three-dimensional configuration of the shape. For that purpose, spatial rules are applied. These two phases will define a referential structural basis that can be improved by the addition of other geometrical qualities of the biological structures (roughness and textures). These additional qualities are decoded separately through supplementary grammars.

First Phase

Structural Base Definition

The generation of the structural base defines the geometric mesh of the shape. The shape and its structural elements should follow proportional and geometrical requirements. The reproductive process of elements addition that defines the growth process follows a particular expansion pattern (spiral or wave). Its presence is so intense that it is responsible for the shape configuration and its internal arrangement. It works as a hidden identity that controls proportion and geometry. Thus, the hidden rules will start by defining an expansive pattern. Its definition is made through levels and sublevels of expansion. They will control the order of magnitude of the structural elements and shape (Figure 20.2). After defining the proportional relations that will prevail the design process proceeds with the definition of the referential shape. For that purpose, an expansion angle and referential points located in its interior are defined. These points are the guidelines for the shape contour definition (Figure 20.3). The number of expansion levels and the amplitude of the expansion angles will influence the diversity of shape configuration.

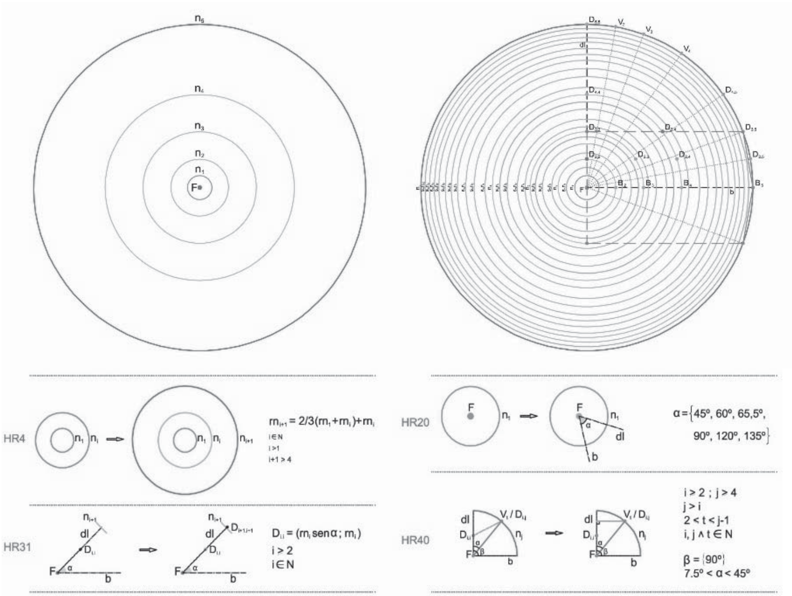


Figure 20.2

Structural base definition through an expansive wave pattern: proportional pattern implementation and examples of hidden rules.

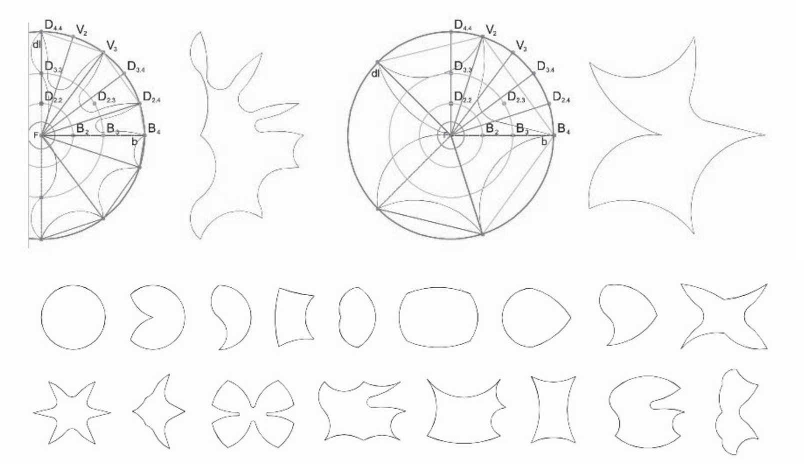


Figure 20.3

Referential shape definition: examples of shape diversity achieved by the design process.

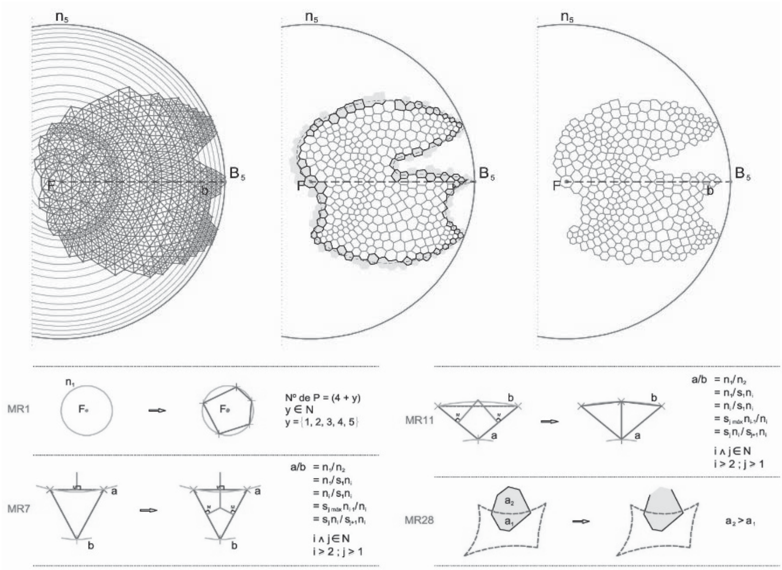


Figure 20.4

Shape materialisation: examples of rules.

After the shape definition the materialisation rules will fulfil the shape with structural elements. The generation of these elements follows the principles of the Voronoi diagrams for centroidal configuration.[13] The shapes will be defined through a growth process from the generator centre to the referential boundaries of the shape. These elements will reflect the proportional relations defined by the hidden rules (Figure 20.4).

Second Phase

Spatial Rules

The spatial rules made the transference of the two-dimensional mesh generated in the first phase for a curved surface in space. However, the surface choice is not random. It should reveal a centroidal configuration in order to be referenced on the generator centre of the structural base and should be characterised by concave and convex boundaries. With these geometrical requirements three geometrical surfaces were identified: sphere, torus and cone. In order to develop structures with a shelter configuration, the sphere and torus surfaces are studied divided in half. The surfaces can reveal several amplitudes being these referenced with the magnitude values of the golden ratio. Other geometrical configurations can be explored using the arc amplitudes of the torus. On the one hand by exploring the possibility of mix together different arcs amplitudes through a gradient effect. On the other hand, allowing the possibility of put the generator centre in different coordinates of the z-axis. Another option to take into account is to split the arc in half and recombines both parts by opposition (Figure 20.5 and 20.6).

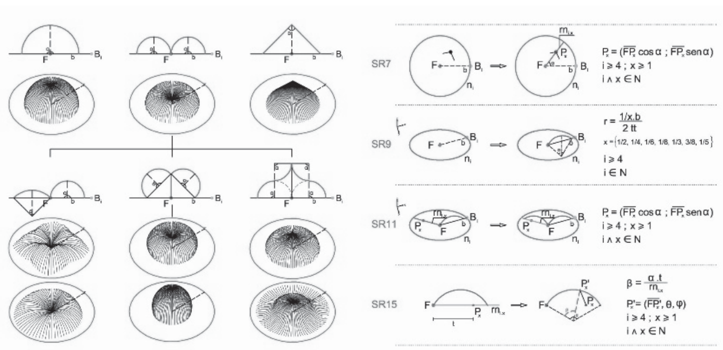


Figure 20.5

Three-dimensional shape configurations: spatial rules examples.

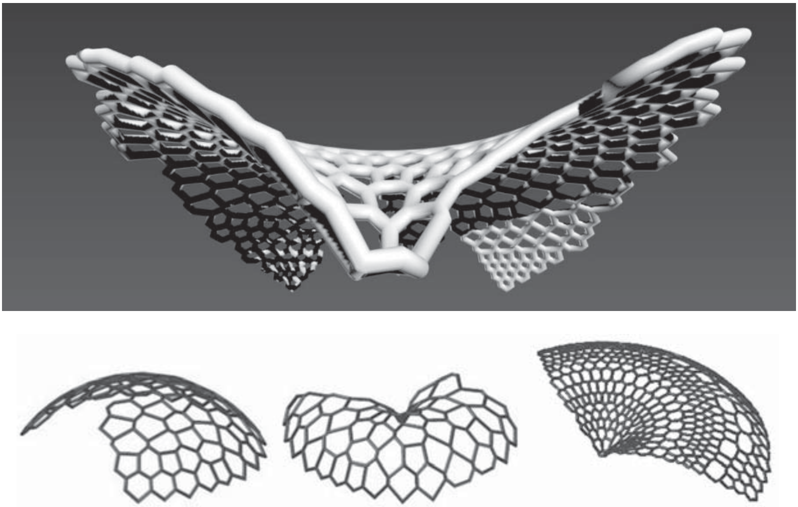


Figure 20.6

Examples of structures generated with the spatial rules of the drawing tool.

Supplementary Grammars

As mention before the supplementary grammars are individual set of rules that could enrich the morphological pattern of the shape. These grammars work in two distinct fields increasing the roughness effect and generating textures. They reveal complementary rules that can be applied in both phases of the main generation process.

The Roughness Effects

One of the most relevant qualities of the biological structures' morphology is the roughness effect. The biological surfaces show dynamism. They emanate vibration. According to Christopher Alexander[1] this quality can only be achieved if the structural shapes are disposed in space by full freedom. The freedom generates irregularity and it only can be achieved by avoiding any kind of repetition. So, the roughness effect requires spatial irregularity. It means that the structural elements should avoid sharing spatial coordinates or a regular surface. Due the fact that the expansion levels used by the hidden rules are regular rings, that regularity tends to pass to the structural shapes as their number increases. This regularity influences the structural shapes. On the one hand, they start to reveal the expansion levels too obviously. On the other hand, some of the straight lines that define the shapes boundary are perfectly pointed to the generator centre. So, in order to break this regularity and increase the vibration of the geometrical mesh, the structural shapes boundaries need some changes. For that purpose, the grammar proposes the following approaches: 1) the displacement of the boundaries nodes; 2) the nodes defragmentation in curved elements and 3) the replacement of the straight lines by curved lines (Figure 20.7).

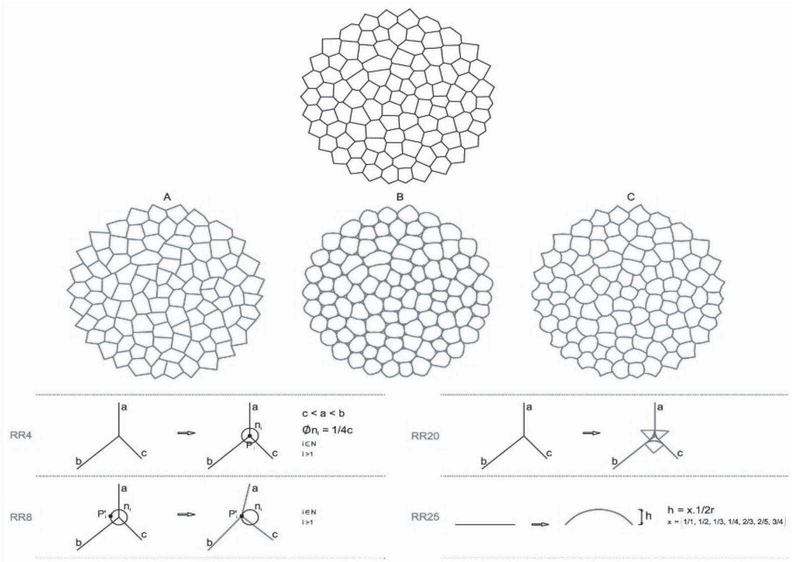


Figure 20.7

Roughness effect. (A) Nodes displacement; (B) Nodes definition through curved elements; (C) Boundaries defined by curved lines.

Textures

The biological structures are characterised by textures. The textures could be achieved by at least two different approaches: by boundaries thickness (which requires the use of the weight grammars algebra)[14] and by the internal filling of the structural shapes. However, their generation should contain the following geometrical requirements: reveal a pattern based on alternate repetition by using contrast strategies and generate a gradient pattern that highlight the generator centre.

The approach based on the boundaries thickness can be applied following two types of patterns compact pattern and ramification pattern. The compact pattern works with the entire shape contour. In turn, the ramification pattern uses the shapes boundaries as referential guides to generate a linear and fluid pattern from the shape origin to its periphery (Figure 20.8 and 20.10). As regards to the approach based on the internal filling of the "cell", it can reveal several configurations. These can be work isolated in the structural shape interior or extended to the other adjacent shapes (Figure 20.9). The textures definition is made over the two-dimensional plan of the structural base. When transferred to the three-dimensional surfaces through spatial rules they require tridimensionality configurations that can be obtained by extrusion.

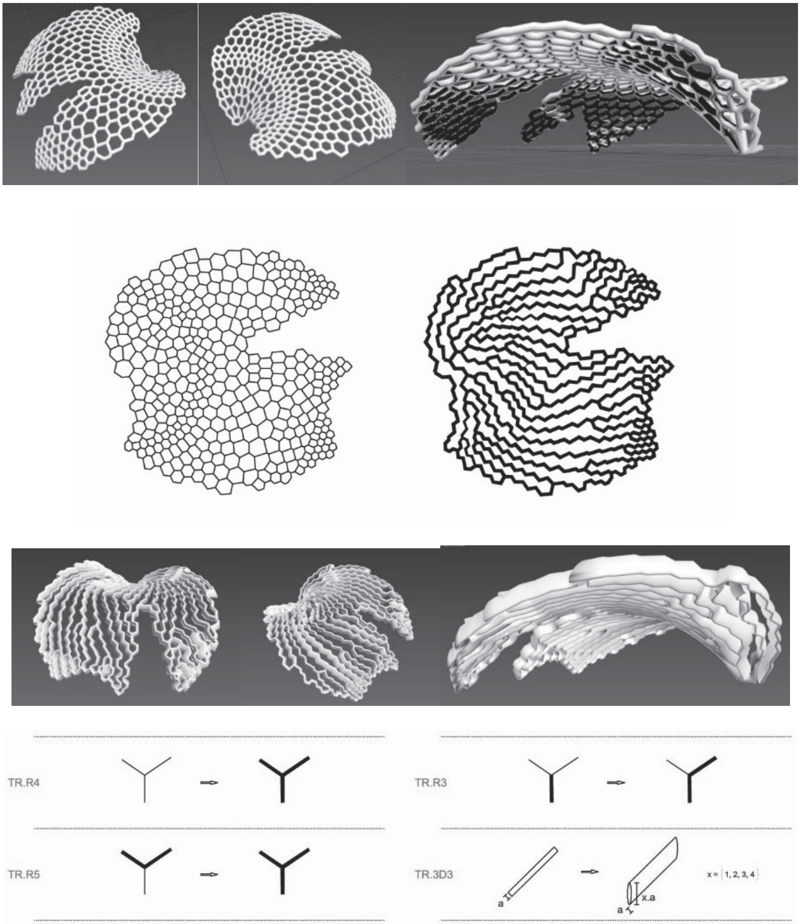


Figure 20.8

Shape transformation using a ramification pattern.

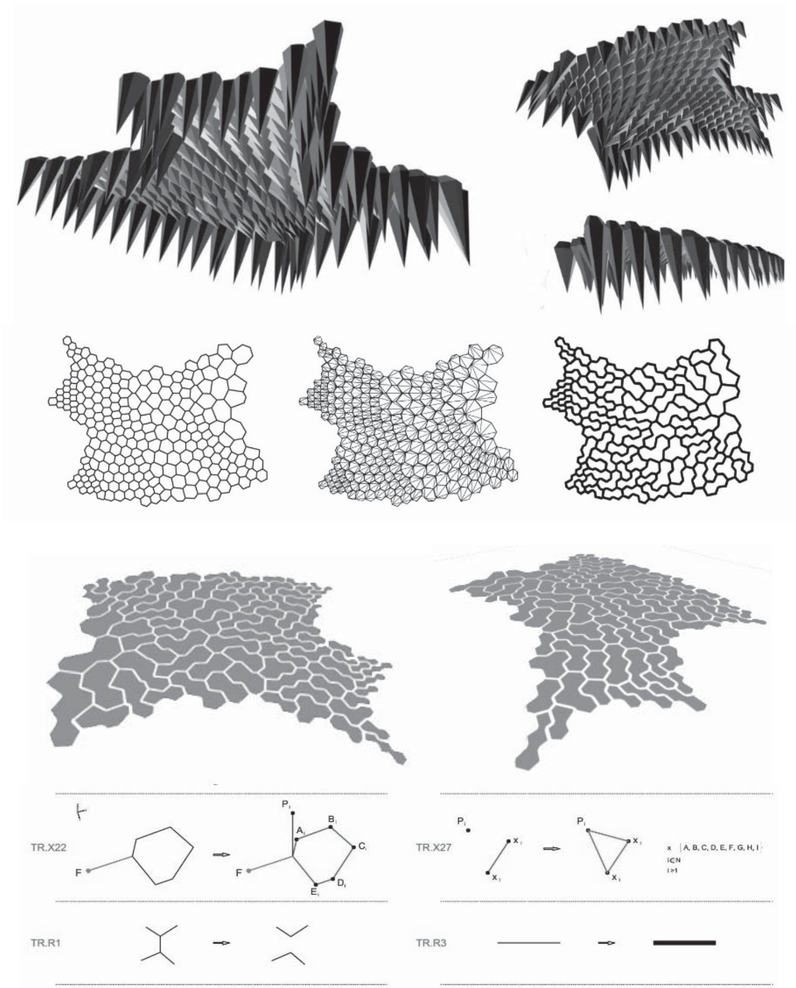


Figure 20.9

Shape definition through a compact pattern using a process of "cells" extrusion (pyramids) and a process of "cells" aggregation.

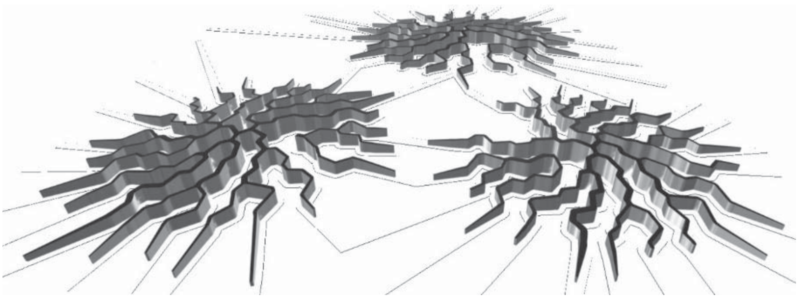


Figure 20.10

Shapes arrangement defined through a ramification pattern.

Results

The drawing tool proposed achieves the research main goals. It generates structures of architectural purpose that reveal simultaneously in the same structure the geometrical and organisational qualities of the biological morphologic identity that have been identified. The structural elements are composed of shapes of triangular derivation with local symmetries arranged through an expansive shape and with overlapped boundaries. The proportional relation between elements, expansive levels and shape configuration reveals harmonious magnitude values and it is implemented through a recursive methodology. The main shape configuration and its boundaries are defined by concave and convex surfaces. The tool is also able to generate shape diversity with the same morphological configuration and without copying and existing structure.

The addition of the supplementary grammars qualities enriches and increases the shape diversity. It uses the structural configuration in order to transform the shape appearance without influence the structural cohesion and its legibility. Their implementation allows exploring the shape configuration at another level. It shows that the textural patterns of biological structures result from the application of at least three geometrical requirements (spatial irregularity, contrast and alternated repetition). They should be defined over the structural configuration and must follow its geometrical requirements. It means that they are a quality that also works through recursion.

Conclusions

In the ecological field, the morphological divergence between human and biological structures comes from a design problem; more precisely it deals with an identity gap. The biological structures which are the highest ecological reference in human design share a morphological identity. It means that the ecological shape should follow a morphological pattern. To achieve that identity, it is imperative to analyse and understand the design process that generates it. It requires the identification and understanding of the organisational process (growth), the geometrical qualities associated to it (the inventory) and a generative design process to combine them. The combination of these three factors is crucial to generate shape diversity with the same morphological identity.

If architecture aspires to have a participative role in the ecological field it should also share this identity. The drawing tool developed by the study of its morphological pattern allows architects and designer the freedom of experience a biological design process without the need to resort the copy of an existing structure. It also allows experiencing the process, with which the morphology of the biological structures reaches it spontaneous integration in the environment and the geometrical organisation behind their self-supporting structures. To achieve an ecological goal at the construction level able to avoid material optimisation due to the high irregularity of the shape, a fabrication process based on 3D printing or bioprinting will be the most appropriate. However, this hypothesis still requires a collaborative effort with other areas of science to achieve structures with multifunctional behaviour (materials science, synthetic biology, metabolic processes, structural and fabrication engineering). It is a future intention continuing to enrich the drawing tool with other morphological qualities that may be identified. The exploration of the design tool through a three-dimensional platform by the development of a computational plugin and a fabrication process associated to it is also a future goal.

References

1. Alexander, Christopher, *The nature of order: An essay on the art of building and the nature of the universe, book 1 - The phenomenon of life*, The centre for environmental structure, California, 2001.
2. Alexander, Christopher, *The nature of order: An essay on the art of building and the nature of the universe, book 2 - The process of creating life*, The center for environmental structure, California,

2003.
3. Gruber, Petra. *Biomimetics in architecture: Architecture of life and buildings.* Springer Vienna Architecture. Vienna. 2010.
4. Mazzoleni, Llaria. *Architecture follows nature. Biomimetic principles for innovative design.* CRC Press. Florida. 2013.
5. Hensel, Michael; Menges, Achim & Weinstock, Michael. *Emergence: Morphogenetic design strategies.* Architectural Design. Vol 74 No 3. John Wiley & Sons. London. 2004.
6. Camazine, Scott; Deneubourg, Jean-Louis; Franks, Nigel R.; Sneyd, James; Thereulaz, Guy & Bonabeau, Eric. *Selg-organization in biological systems.* Princeton University Press. New Jersey. 2001.
7. Hensel, Michael; Menges, Achim & Weinstock, Michael. *Techniques and technologies in morphogenetic design.* Architectural Design. John Wiley & Sons. London. 2016.
8. Menges, Achim. *Material computation: Higher integration in morphogenetic design.* Architectural design. John Wiley & Sons. London. 2012.
9. Oxman, Neri, *Material-based design computation*, MIT, Massachusetts, 2010.
10. Vieira, Celso. *Which is more fundamental: processes or things?*, Aeon magazine. 2017. https://aeon.co/ideas/which-is-more-fundamental-processes-or-things (january 16, 2018)
11. Thompson, D'arcy Wentworth, *On growth and form: the complete revised edition*, Dover Publications, New York, 1992.
12. Stiny, George, "Introduction to shape and shape grammar", *Environmental and Planning B*, vol. 7, pp. 343–351, 1980.
13. Aurenhammer, Franz; Klein, Rolf & Lee, Der-Tsai, *Voronoi diagrams and Delaunay triangulations*, World Scientific Publishing Company, London, 2013.
14. Stiny, George, "Weights", *Environmental and Planning B: Planning and desgn*, vol. 19, pp. 413–430, 1992.

CHAPTER TWENTY-ONE

FOUR-DIMENSIONAL OBJECTS, CELLULAR AUTOMATA AND VIRTUAL REALITY: THE HYPERCOCOON PROJECT

VICTOR SARDENBERG, ISADORA TEBALDI, EMILIO BIER, NICOLLE PRADO

Introduction

Architecture has, at its core, representation tools that are able to reduce 3D objects in 2D drawings. From the Renaissance, especially through the work of Alberti and Dürer, plans and sections were instrumental to reduce one of the dimensions to understand the architectural object and its disciplinary problems: mass *vs*. voids, parts *vs*. whole, inside *vs*. outside.

Historical References

Alberti

The invention of Architectural Design by Alberti separated the builder from the architect. The architect became the intellectual author through the use of drawings, especially one very specific kind: orthogonal representations. Mathematically, it would be a kind of perspective where the observer is located at an infinite distance from the object. One of the first developments of this kind of drawing was made by the early Italian Renaissance painter, Piero della Francesca, in the 15th Century. Alberti, in his treatise, argued that architects, unlike painters, should not use vanishing point perspectival views because of its lack of "consistent lines", "true angles", and "real measurement, drawn to scale".[1] Since then, for centuries, architects were able to design three dimensional objects via two dimensional drawings.

Dürer

While Alberti avoided any kind of drawing in his treatise in favour of mathematic and algorithmic instructions to reproduce illustrations, Albrecht Dürer made large use of drawings in his treatises. At the beginning of the 16th Century, the artist and theorist born in Nuremberg, "adopted the term diagram (Aufgerissen or Aufriss, 'what divides and makes visible', or simply 'outline') to refer to the sectioning of reality through perpendicular planes and the translation of objects into series of coordinates in space"[2]. Also, in his study of human proportion, Dürer developed a geometrical system to represent our bodies that operates through orthogonal drawings.

The historical period from the Renaissance until now has been a history of translating spatial objects into orthogonal drawings or, in other terms, reducing or extrapolating dimensions. Our interest in both Duerer and Alberti lies in how both built the cornerstones of techniques to slice reality.

Duchamp and The Large Glass

The problem of the representation of 4D objects was also grasped by modern artists, mostly identified with the Cubist painters.[3] In an interview,[4] Duchamp declared that he was very interested on this mathematical problem after reading the work of Gaston de Povolowski, and that the bride in the "The Bride Stripped Bare by Her Bachelors, Even" painting, also known as "The Large Glass", was a projection of a 4D object.

Virtual Reality and the Contemporary Extrapolation of Dimensions

Virtual Reality

With the recent advances of graphic cards and pixel density on screens, it is already possible to argue that nowadays we have a sufficiently acceptable Virtual Reality experience with customer level solutions like HTC VIVE and Oculus Rift. According to the philosopher Elizabeth Grosz,

> perhaps the most striking transformation effected by these technologies is the change in our perception of materiality, space, and information, which is bound directly or indirectly to affect how we understand architecture, habitation, and the built environment.[5]

With the popularization of Virtual Reality goggles as a visualization tool, we have an immersive experience of virtual volumetric objects with one big difference in the way we experience reality: everything that was solid and static in our physical world becomes variable and malleable in our experience with digital materials.

Higher Dimensions

The project that culminates from this research produces the phenomenological experience of inhabiting a 4D object. Usually, the 4D hyper-object is represented as a succession of cubes that are connected by lines in its vertices as seen in Figure 21.1. This way of representing it is an abstract extrapolation. The problem of imagining and producing the image of realities and objects with more or less than our three-dimensional experience of space has been challenging humanity for a long period of time.

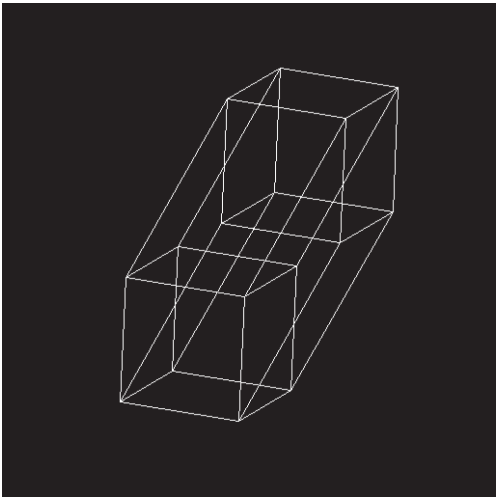


Figure 21.1

4D Hypercube presented as cubes connected in the vertices with lines by Alan B. Scrivener.[6]

A good example in literature is the book "Flatland" by Edwin Abbott Abbott.[7] First published in 1884, the novel features a square as a first-person narrator that describes in detail the experience of his two-dimensional world, as well as the social implications of such a reality. The character, in different manners, visits three dimension and single dimensions worlds and, in all of them, due to his bad luck, his ideas of worlds with even more dimensions are taken as delusions of a mad man, in an indirect reference to Socrates interpretation of Plato's Cave, where he asserts that those who live in the world of shadows (2D) would violently react to the one who come back after seeing the world of objects (3D).

It is definitely counterintuitive to imagine objects with four dimensions because there are no examples of such things in the way we experience our world. So, through the use of CA and Virtual Reality, this project offers the possibility of inhabiting a 3D slice of a hyper-object.

Cellular Automata Hyper-Object

The representation of Cellular Automata systems is usually made by extrapolating one dimension. To exemplify: 1D CA is usually stacked to produce a 2D image. A 2D CA is stacked to produce a 3D volume. Also, 3D CA systems are somehow represented as a series of 3D cubes because of our inability to imagine a 4D reality and what would be a 4D object, which is called a hyper-object.

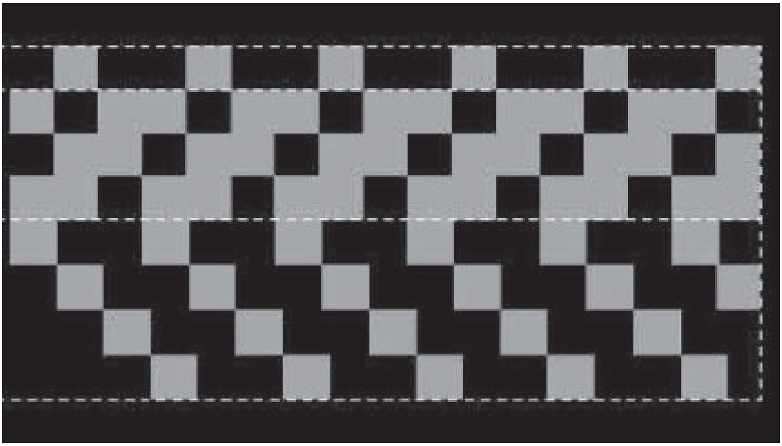


Figure 21.2

1D (linear) CA System Stacked.

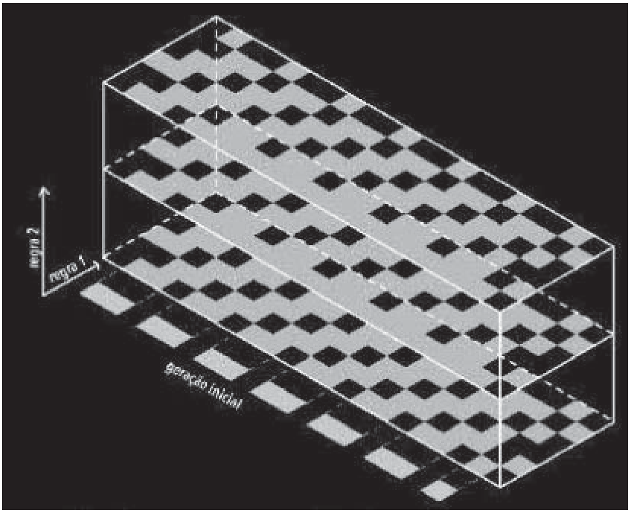


Figure 21.3

2D (planar) CA System Stacked.

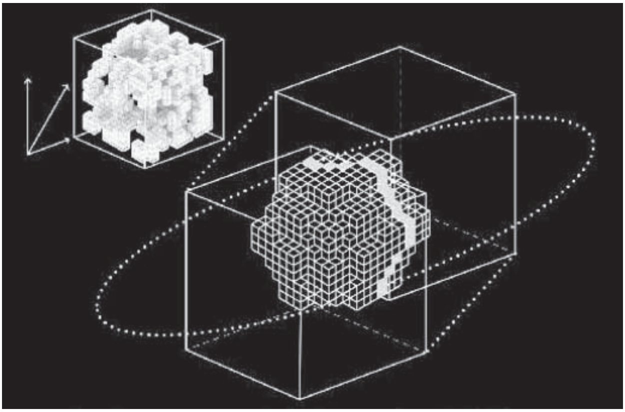


Figure 21.4

3D (Volumetric) CA System as a Hyper-object.

The premise of the project is that if an orthographic drawing is a section of a 3D object, a 3D VR experience can be seen as a section of a hyper-object. Here, the forms created are not merely the development through time of the

CA system, but also the result of the interaction between the subject and the system in real time. The project operates in two modes:

A. The user position changes the initial rule of the CA system, or;
B. The user position changes the state of nearby cells.

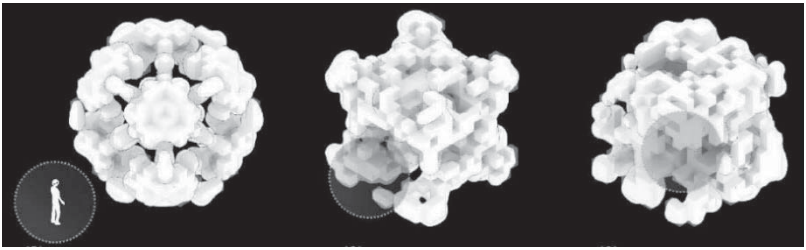


Figure 21.5

The changes in the CA system according to the user's position.

To produce an architectural object, the project creates a virtual cocoon whose dimensions are 6mx6mx6m. To give form to the system, two methods were developed in parallel: (a) the cell states inform Voxels, and (b) the cell states charge a field that generates a Metaball mesh, according to the computational power available. The whole experience was produced using Rhino, Grasshopper, Python, Mindesk VR, and an HTC VIVE goggle.

This research was developed during the workshop "Form finding and generative systems" realized by LAMO (Laboratório de Modelos e Fabricação Digital/Laboratory Models and Digital Fabrication), within the Post-Graduation Research PROURB at Rio de Janeiro Federal University, which was held from 28th August to 6th September 2017. The workshop goal was to compare different form-finding techniques (CA, GA, L-Systems, and Shape Grammar).

Conclusion

The researchers realized that CA is a valid tool for multidimensional form making as it is able to create n-dimensional objects. Also, VR goggles are very intuitive to experience such objects, thereby pushing us to produce images of counter-intuitive worlds and enabling us to be more comfortable with it.

This speculation becomes relevant for architectural discourse at the very moment when we are faced with the popularization of Virtual Reality, which introduces the possibility of infinitely adaptable geometries and the constant feedback between user and architectural object. If Architecture is a discipline that operates not only via physical buildings but has as its core drawings—and we believe that is the case and this is the definition we depart from—and "the virtual reality of the computer space is fundamentally no different of writing, reading, drawing or even thinking",[8] Virtual Reality seems like an absolutely valid medium for architecture—be it for designing, visualizing, and/or inhabiting these spaces.

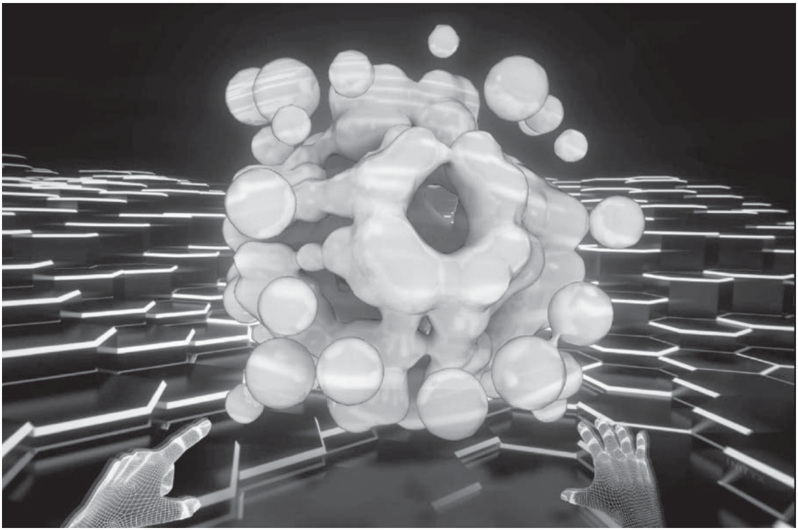


Figure 21.6

Artistic representation of the Hypercocoon as Metaball mesh in Virtual Reality.

References

1. Carpo, Mario. *The Alphabet and the Algorithm.* Cambridge: MIT Press. 2011.
2. Marullo, Francesco. *Logistics Takes Command*. Log Magazine, issue 35, New York, Fall 2015.
3. Bodish, Elijah. *Cubism and the Fourth Dimension* in The Mathematics Enthusiast, Volume 6, Number 3, University of Montana, July 2009.

4. Cabanne, Pierre. *Dialogues with Marcel Duchamp.* Penguin, 1971.
5. Grosz, Elisabeth. *Cyberspace, Virtuality and the Real.* in "Architecture from the Outside". Cambridge: MIT Press, 2001. p. 76.
6. Scrivener, Alan B. *Visualizing 4D Hypercube Data By Mapping Onto a 3D Tesseract.* ACM/SIGGRAPH '96 Conference held August 4–9, 1996 in New Orleans, Louisiana.
7. Abbott, Edwin Abbot. *Flatland*. Princeton: Princeton University Press, 2015.
8. Grosz, Elisabeth. *Cyberspace, Virtuality and the Real.* in "Architecture from the Outside". Cambridge: MIT Press, 2001. p. 76.

CHAPTER TWENTY-TWO

Z-TOLERANCE: THREE-DIMENSIONAL ABSTRACT REPRESENTATIONS OF THE MIGRATION ISSUES IN EUROPE

CANAN ALBAYRAK COLAÇO, RUI COLAÇO

Introduction

Z-tolerance is the name of the art installations designed and manufactured by the authors as part of an exhibition proposal, aiming to raise awareness to the current migration issues in Europe. Migration has gained prominence in the international agenda; it is now the highlight of sensitive debates and increasing media focus. European migration has been studied in detail in literature and the resulting issues are commonly represented by charts, numbers, statistics, and percentages, e.g., proportions of lost lives *vs*. safe arrivals, number of foreign-born people as a percentage of the total population, number of migrants refused and allowed, etc. However, some may argue this approach only reduces this delicate topic into counting noses. This paper and its related research propose the use of an abstract visual language to represent different migration.

Formal methods were utilised, specifically parametric design, in the process of transforming migration aspects that are normally represented by daily language into a visual language. Different aspects of the migration and refugee issues are represented not only through the final form but also through the stages of form finding process. Parametric modelling, manual mathematical calculations and photographic techniques are used for perception-based aspects of anamorphic perspective.

In literature, several approaches to the migration phenomena exist.[1] Within the scope of this study, "migrant" is an umbrella term that refers to someone undergoing a change of residence, permanently or not, which involves a change of social, economic and/or cultural environment. Migration is driven by both attraction and repulsion factors. Environmental degradation and unexpected natural disasters urge people to seek refuge outside their land. Other drivers of international migration are disparities in economy, democracy, governance, human rights and human security. Poverty, fear, and continued conflict push people to search for better opportunities in more stable and developed regions. The phenomenon of migration is an integral part of reality. People have always moved, and people will continue to move.

For centuries, Europe was a region of substantial emigration, nowadays the region projects an image of opportunity and ends up a favourite destination region for many migrants from all over the world. In fact, European countries need additional cheap and flexible labour, and migrants are willing to take the jobs that citizens will not do. In the past years, after vast numbers of people travelled across the Mediterranean Sea streaming into the European Union (EU), migration in the region has been referred to as the European migrant crisis, presenting European leaders and policymakers with their greatest challenge since the 2008 debt crisis.[2] Europe is now considered the most dangerous destination for irregular migration in the world, and the Mediterranean the world's most dangerous border crossing.[3] However, despite the rising number of deaths, the EU's response has been more focused on securing its borders than on protecting the rights of migrants, especially refugees.[4] Furthermore, with far-right movements rising in several nations of Europe, and fear of Islamic terrorism spreading through its population, the future of these people remains uncertain.

Installation 1

From Turkey to Portugal, Golden Visa and Sephardic Jews

Migration does not necessarily need to represent a state of crisis. On the contrary, some countries promote immigration by providing advantageous legal rights to migrants, such the offering of golden visas. Since 2012, Portugal is giving right of residence to foreign investors in the country, which include freedom of travel around the Schengen area and entitlement for Portuguese citizenship after six years.[5] A large demand for Portugal's golden visa program originates from Turkish citizens, who perceive it as an insurance against the uncertainties brought up by an increasingly repressive political regime, lack of freedom of expression and unstable economy in their country[6]. The fact that Portugal is also offering nationality to descendants of Sephardic Jews adds to the flow of people between these two countries, since most of them had escaped to the Ottoman Empire when expelled from the country in the 15th century.[7] The latter instance exemplifies how drifts in tolerance levels may fully reverse migration patterns, which are dynamic by nature.

Installation 2

From Morocco to Spain, Strengthening Borders

In many instances, countries work hard to strengthen their borders in order to prevent the flow of unwanted migrants. The situation in Melilla clearly contrasts with the previous example. Europe's only land border with Africa, between the Spanish enclave of Melilla and Morocco is one of the most fortified barriers on the world.[8] Migrants fleeing poverty and conflict from across Sub-Saharan Africa see Melilla as a gateway to Spain and Europe, and a somehow less hazardous option to crossing the Mediterranean.[9] Despite these migrants being fully aware of the risks involved in attempting to jump the fences, many still choose risking their lives crossing, putting themselves in the hand of unscrupulous human smugglers.[10]

Installation 3

From Tunisia to Italy, Crossing Forbidden Borders

Many migrants choose crossing the Mediterranean Sea as a way to enter the industrialised world. The number of illegal border-crossing to the EU increased sharply in 2011, as thousands of Sub-Saharan African migrants from Tunisia began arriving at the Italian island of Lampedusa, following the onset of the Arab Spring and the unrest of the post-Qaddafi era.[11] 2017 was the deadliest year for migrants trying to crossing the Mediterranean. A crackdown on illegal migration routes such a route over Libya and Turkey only lead to emergence of new ones. In this context, Tunisia started to attract attention for the ones desperately attempting to reach safety or a better life in Europe. Until the late 1980s, Tunisians did not need a visa to enter Italy. Many used to be seasonal workers, returning home yearly. Nowadays, Tunisian migrants are at the mercy of human traffickers.

Methodology

Islamic Geometric Patterns

Islamic geometric patterns were chosen to represent the three above mentioned instances of migration issues, as a common element capable of depicting all countries involved. Geometric patterns are the mostly used visual element of Islamic art and architecture.[12] Most of the Islamic geometric patterns fall into three families: fourfold, fivefold or sixfold systems and their multiples; generating them involves basic geometric techniques.[12] A compass and ruler (or a piece of rope that would serve as both) are the only instruments required for constructing such geometric designs; that, and extensive practical knowledge of geometry.[12] The use of formal methods and geometry is utilised for the creation of single motives and their perfect combination into a larger scale composition.

Most geometric patterns in Islamic art and architecture are based on repetition of a single motif that is tessellated into a grid. Instead of designing one single element to element to decorate an entire wall, the surface is divided into a grid of squares and hexagons, and then the individual motif is repeated in each unit.[12] Symmetry is an important design principle and an outcome of repetition and grid usage.[13] These easily observable and regular basic design rules of Islamic geometric patterns make them very suitable for algorithmic generation.[14, 15]

The geographic distribution of Islamic geometric patterns, namely in North Africa, South Europe, and the Middle East, overlaps with the regions wherein the flow of people is observed within the context of the recent European migrant crisis. Therefore, it is possible to match the countries (three migrant-sending and three migrant-receiving) with Islamic geometric patterns selected from each one.

Anamorphosis

While dealing with migration, it is very important to understand how changing points of view shifts perception, hence allowing for understanding. Anamorphosis delivers the same message through physical distortion perspective. Anamorphosis has three main meanings:

1. A drawing presenting a distorted image which appears in natural form under certain conditions, as when viewed at a raking angle or reflected from a curved mirror;

2. The method of producing such a drawing;
3. The gradual change in form from one type to another during the evolution of a group of plants or animals.[16].

According to the first definition, there are two main types of anamorphosis (Figure 22.1). In oblique anamorphosis, distorted images of a certain form gain shape when observed from a special posting, thus requiring perspectival distortions.[17] In catoptric anamorphosis, the image must be seen reflected by a distorting mirror or lenses, involving optical transformations.[17] Both types strictly follow the laws of perspective and optics. Their rule-based nature makes them very proper for algorithmic generation.[18] Parametric and digital modelling can be used for the perspectival and optical transformations and for calculating the positioning of the observer and testing the perceived effects.[18]

Figure 22.1

Examples of perspective anamorphosis (oblique) and optic anamorphosis (catoptric).[17]

In anamorphic art (drawing or sculpture), the image is distorted so that it is hard to recognise at first glance. Only when viewed from a specific standpoint, or when using a special reflective device, the intended form becomes recognisable. Therefore, while contemplating anamorphic art, it is important to observe and behold rather than expect.[17]

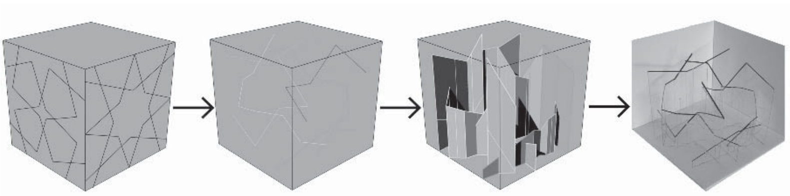
In the present research, oblique anamorphic perspective was utilised to design three-dimensional forms that reveal two specific Islamic geometric patterns perpendicular to one another: an observer who is walking around a Z-tolerance installation piece, will perceive the gradual change in form from one type of Islamic geometric pattern to another. The positive message of the dynamic perceptions depending on the observer vantage point aims to reflect the way perceived differences arise from mere dissimilar perspectives, even when looking to the same object/concept.

Parametric Design

Parametric design formalises design process through parametric definition of the design parts and their relationships by means of rules defined mostly algorithmically, which requires an explicit thinking of design[19]. Comparing to computational models that limit designer control and restrict the range of expressible forms, the flexibility of parametric modelling allows the designer to explore form as a field of possibilities.[20] Consequently, the role of the designer is more than a toolmaker; the designer is also the decision-maker through every stage of the model.[20]

In the present research, both the final form and the stages of the form finding process are used for abstraction of the migration issues in Europe. Formal methods are used to translate the migration aspects, normally represented by daily language, into a visual language.

The authors developed a parametric model that involves of two stages, as illustrated in Figure 22.2. The first stage is the generation of the abstract geometry that is the outcome of merging two Islamic geometric patterns into a three-dimensional anamorphic form. The second stage comprises the materialisation of anamorphic form, manufacturing process and testing design alternatives.



Stage 1 Stage 2
Islamic Anamorphic Form Materialisation of Form Final Result
Geometric Patterns

Figure 22.2

Design process exemplified through Installation 1.

Stage 1

Merging Islamic Geometric Patterns into Anamorphic Form

Firstly, an outlining cube is parametrically defined. A two-dimensional Islamic geometric pattern from the migrant-sending country is selected and defined on the *y=0* plane; another pattern from the migrant-receiving country is defined on the *x=0* plane. The minimum number of control points is calculated in order to draw and merge the two-dimensional patterns into three-dimensional anamorphic form. The control points of the first geometric pattern are merged with the nearest control point of the second one.

Since the first geometric pattern is defined on the *xz* plane and the second on the *yz* plane, the control point resulting from merging these two control points automatically gets the *x* value of the first geometric pattern and the *y* value of the second pattern. However, the key point that would characterise the final geometry is the definition the *z* values for the convergence of the control points. In case two control points do not share the same *z* value, either the *z* values of the first pattern yield to the values of the second, or the opposite. Since migration represent a flow of people from a migrant-giving country to a receiving country, the pattern from the migrant-giving country is adapted to the pattern of the migrant-receiving country with some boundary conditions.

For the convergence of the control points' *z* positions, a tolerance value named as Z-tolerance was parametrically defined. Defining the optimum Z-tolerance is an important design decision. For instance, if the Z-tolerance value is too small, the geometric patterns cannot merge into a unique three-dimensional form. Furthermore, the value cannot be so high that the Islamic geometric patterns are deformed and lose their primary design principles. As illustrated in Figure 22.3, the tolerance value is parametrically defined to generate different design alternatives in relation to changing Z-tolerance values that reflects social and cultural exclusion, integration, and assimilation. The present project is named after this design step and its metaphoric representation.

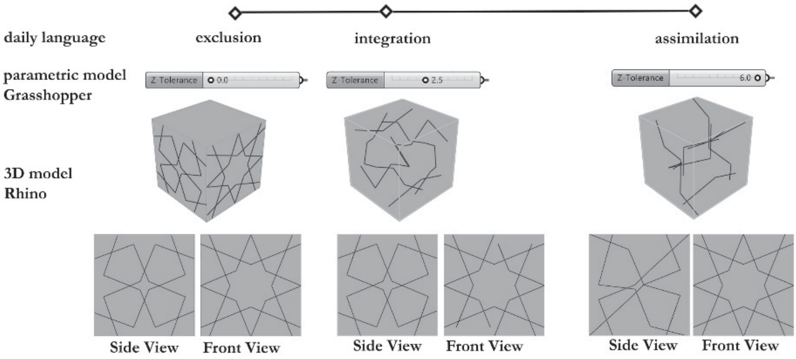


Figure 22.3

The effect of changing Z-tolerance value exemplified through Installation 1.

Merging of two different geometric patterns into a three-dimensional form also reflects tensions arising from merging of different cultures. For the generation of the final forms of the three installation pieces, the integration case was chosen over exclusion and assimilation. Therefore, in the design step of repositioning the *z* value control points of the migrant giving country to the migrant receiving country, the Z-tolerance values that would not deform the characteristics of the Islamic geometric patterns are preferred. The tolerance values that would result in a fit into the second pattern with a percentage above ninety were settled for. Thereby, in the generated final form, parts of the pattern selected from the migrant-receiving country are missing, as illustrated in Figure 22.3, front view of the integration case.

Despite the existence of missing parts, patterns of the migrant-receiving country are still visually readable. Conversely, when a group is expected to fully come to resemble another group, cultural bereavement may result, as seen in cultural assimilation cases. Accordingly, in migration, assimilation is a much-disputed topic, often treated as an obstacle for the enrichment and diversity of cultures.

Stage 2

Materialisation of Form

The output of the first stage of the design process, i.e., merging Islamic geometric patterns into anamorphic form, is an abstract form. The second stage of the design is related to the materialisation of this form as a buildable structure fabricated by means of CAM technologies. Hence, the abstract form that is composed of three-dimensional floating lines are extruded straight to the *z=0* plane. These extrusions are cut from transparent sheets and black bands are placed on top edges of the transparent sheets in order to make the merged geometric patterns visible. Transparent sheets are placed on a base with engravings that serves as a dock for self-supporting sheets. The thickness of the transparent material, the black bands and depth of engravings are defined parametrically in order to find an optimum solution where sheets may endure momentum without bending, deforming or creasing. Additionally, changing variables related to thickness is exploited in the search for alternatives for increasing visibility of the Islamic geometric patterns.

Results

Three installation pieces are manufactured (Figure 22.4) as an outcome for the search of design possibilities and alternatives. For Installation 1, a pattern from stone carvings of Ak Medrese, in Niğde, Turkey[12] (a crossed bow tie shape that forms a 4-pointed star pattern in the middle) was chosen, as well as a pattern that exists on a tile in the National Tile Museum, in Lisbon, Portugal (8-pointed star pattern). For Installation 2, both a pattern on a wooden door panel in a souk in Marrakech, Morocco (8-pointed star pattern) and a pattern on the tiles of the Alcazar of Seville, Spain (6-pointed star pattern) were used. For Installation 3, a tile pattern from qibla wall of Great Mosque of Kairouan, Tunisia (pattern of square in square), which is a very early example of ceramic tiles,[13] was used together with a tile pattern that exist in Monreale Cathedral, in Palermo, Italy (8-pointed star pattern).

The repositioning of *z* values of the control points is defined within the previously mentioned boundary conditions by finding optimum Z-tolerance values. PETg material was chosen for the transparent sheets since it is clearer and less brittle compared to other transparent acyclic materials.

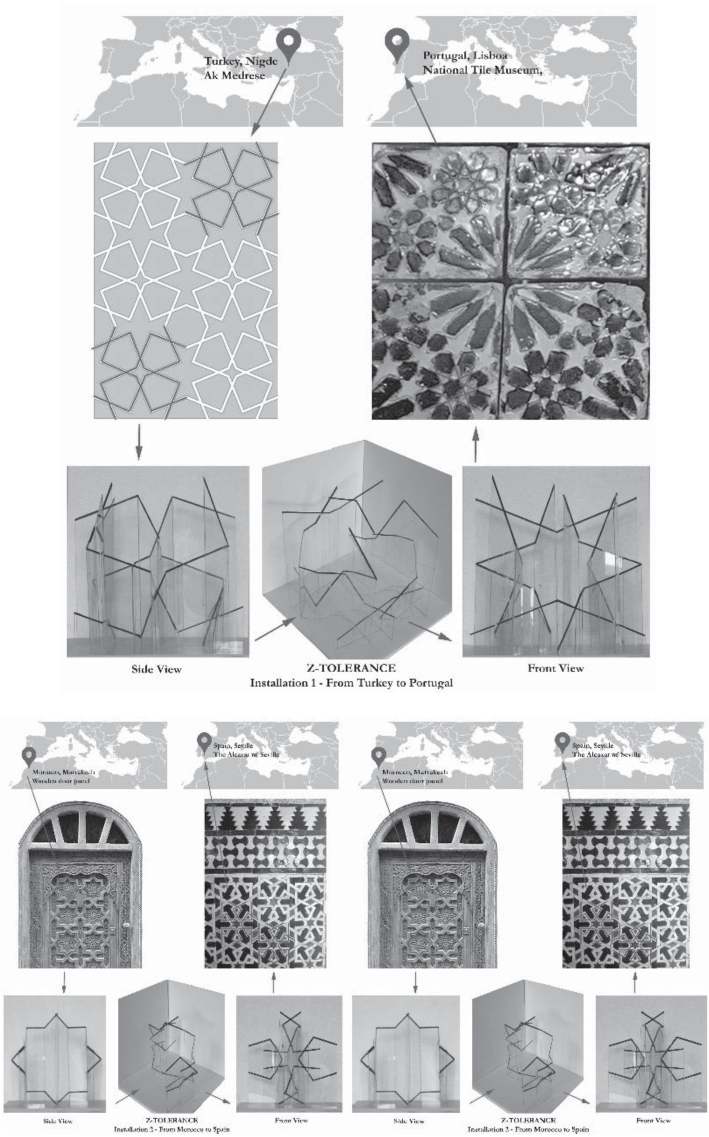


Figure 22.4

Three installation pieces each representing a different migration flow.

Defining the Vantage Points

Vantage point is the standpoint from which something is viewed or considered. Vantage point has the same meaning in anamorphic art. It is the designated point for the observer to stand and view anamorphic art so that the anamorphic image is recognisable.[21] Within the content of this research, two vantage points for each installation had to be defined so that the final 3D form reveals the Islamic geometric patterns. The vantage points were defined by means of three factors: positioning angle, ground elevation and observer-installation distance. In anamorphic perspective, their incorrect definition result in the undesirable deformations that obstruct the observer from recognising the image.

As a result of the rules of perspective, an observer looking to a cube will perceive the back plane of the cube smaller than the front plane, as illustrated in Figure 22.5. However, in order to prevent distortions of the perceived Islamic patterns, the deformation of the back plane of the outlining cube to the front plane has to be negligible. Accordingly, there are two ways to minimise this effect. Mathematically, if the vantage point is at infinity then the distortion disappears. In practice, if the vantage point is reasonably distant, then the resulting distortion may become negligible. Alternatively, if the size of the outlining cube is small enough compared to the distance of the observer then the distortion of the back plane of the cube also becomes negligible.

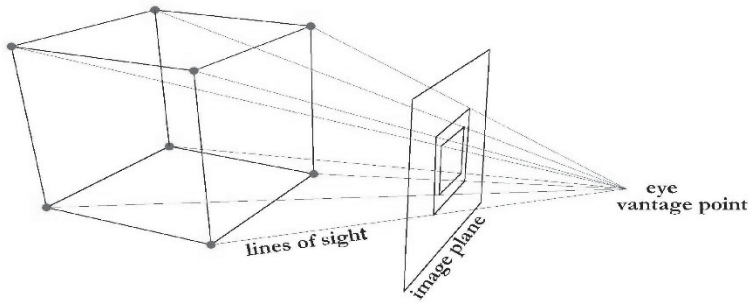


Figure 22.5

Perspective projection.

Within the content of this research, manual mathematic calculations and photographic techniques are used to test the perceived effect of differing vantage points in relation to distortion of the outlining cube and size of the outlining cube. The definition of vantage points, which is the final step after design process, has influence on the first step of design process, which is the defining the outlining cube. Thereby, the design process becomes a closed loop instead of a linear process. The parametric definition of design process, starting with the parametric definition of the outlining cube, makes this research feasible by ensuring easy manipulation and control of the desired outcome via parameters. Parametric design was also utilised for quick visualisation of different materials and sizes.

Discussion

Formal methods and computational processes are well suited for material, environmental and structural constraints since these are translatable into a binary code.[2]. However, recent studies prove that complex, technical, social, and human factors of design (such as cognitive and phenomenological ones) are translatable into a formal language.[20, 23] The design of the Z-Tolerance exhibition contributes to the research of abstraction of meaning and formalisation of cognitive aspects of design, specifically perception. Firstly, both form and the process of form finding are investigated as a way of abstraction of meaning. Different aspects of the migration and refugee issues are represented through the design of form and of the design process itself. The different stages of parametric modelling design contribute to abstraction of migration issues. Secondly, parametric modelling, manual mathematical calculations and photographic techniques are extensively for perception-based aspects of anamorphic perspective.

Conclusions

In this project, three different aspects of migration are represented by three installations. Parametric design and three-dimensional modelling are used for the process of transforming migration aspects, normally represented by daily language, into a visual language. The design process used for this transformation was specially considered so that the process could represent different migration issues. In addition to parametric design, the methodology utilises Islamic geometric patterns and anamorphic perspective. This model can be used for further generation of installations utilising different Islamic geometric patterns.

Future work is planned to focus on algorithmic calculation of the vantage points and parametrising positioning angle, ground elevation and observer-installation distance. In the present work, the outlining cube has not been deformed according to perspective projection. However, for installations of larger sizes the infinite vantage point would be very far, and thus there would be a need to deform the outlining cube along lines of sight, as illustrated in Figure 22.6. This distortion needs to be considered for the observation of both patterns.

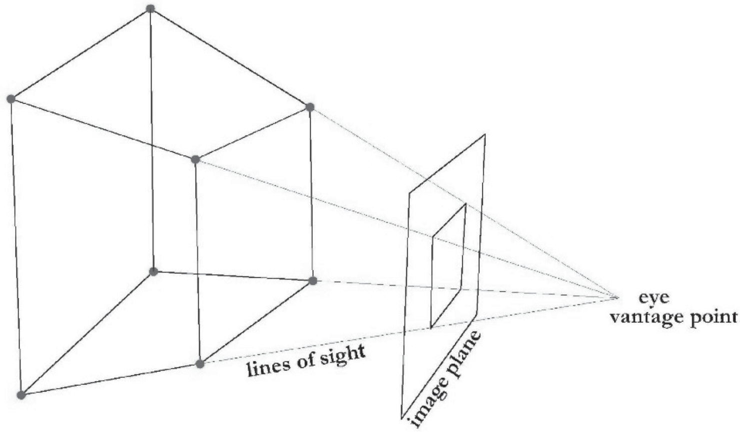


Figure 22.6

Deformation of the outlining cube along the lines of sight.

References

1. Castles, Stephen. "Understanding Global Migration: A Social Transformation Approach." *Journal of Ethnic and Migration Studies* 36, no. 10 (2010): 1565–1586.
2. Nugent, Neill. *The Government and Politics of the European Union (Eight Edition).* UK: Palgrave Macmillan, 2017.
3. Brian, Tara. Laczko, Frank. *Fatal journeys: Tracking Lives Lost During Migration.* Geneva: International Organization for Migration, 2014.
4. Kahanec, Martin. Fabo, Brian. "Migration Strategies of Crisis-Stricken Youth in an Enlarged European Union." *Transfer: European Review of Labour and Research* 19, no. 3 (2013): 365 – 380.
5. Mesquita, Raquel. *Portugal o Novo Paraíso Fiscal Para os Estrangeiros – Regime Fiscal dos Residentes Não Habituais e os Golden Visas.* Lisbon: Universidade Católica Portuguesa, 2013.

6. Cox, Hugo. *Lisbon's Golden Visa Age: Market Boosted by Residency Scheme.* 2017. https://www.ft.com/content/22b887b8-5123-11e7-a1f2-db19572361bb (accessed February 2018).
7. Freire, Manuel Carlos. *Nacionalidade Portuguesa Atribuída a 713 Descendentes de Sefarditas.* 2017. https://www.dn.pt/portugal/interior/nacionalidade-portuguesa-atribuida-a-713-descendentes-de-sefarditas-8730365.html (accessed February 2018).
8. Haas, Hein de. "The Myth of Invasion: The Inconvenient Realities of African Migration to Europe." *Third World Quarterly* 29, no. 7 (2008): 1305-1322.
9. Bosch, Peter. Haddad, Emma. "Migration and Asylum: An Integral Part of The EU's External Policies paper presented at European Centre of Natolin." 2007. http://www.natolin.edu.pl/pdf/FN/FN_3_2007_bosh_haddad.pdf (accessed February 2018).
10. Carling, Jørgen. "Migration Control and Migrant Fatalities at the Spanish-African Borders." *International Migration Review,* 41, no. 2 (2007): 316–343.
11. Boubraki, Hassan. "Revolution and International Migration in Tunisia, Research Report for Migration Policy Center." 2013. http ://www.migrationpolicycentre.eu/docs/MPC-RR-2013-04.pdf (accessed February 2018).
12. Broug, Eric. *Islamic Geometric Patterns.* London: Thames and Hudson, 2008.
13. Broug, Eric. *Islamic Geometric Design.* London: Thames and Hudson, 2013.
14. Sayed, Zahra. Ugail, Hassa. Reeve, Carlton. Palmer, Ian. Purdy, Jon. "Parameterized Shape Grammar for Generating n-fold Islamic Geometric Motifs." *International Conference on Cyberworlds.* 2015. 79-85.
15. Bonner, Jay. *Islamic Geometric Patterns: Their Historical Development and Traditional Methods of Construction.* Springer, 2017.
16. Collins, Dan. "Anamorphosis and the Eccentric Observer." *Leonardo Journal* 25, no. 1 and 2 (1992).
17. Ayoub, Manal Helal. "A simplified Procedure for Anamorphic Sculpture." *International Design Journal* 5, no. 2 (2015): 317- 326.
18. Paola, Francesco Di. Pietro, Pedone. Pietro, Laura. Santagati, Cettina. "Anamorphic Projection: Analogical/Digital Algorithms." *Nexus Network Journal* 17 (2015): 253–285.

19. Woodbury, Robert. *Elements of Parametric Design.* Londan and New York: Routledge, 2010.
20. Colletti, Marjan. *Digital Poetics: An Open Theory of Design-Research in Architecture.* Asgate Publishing, 2013.
21. Salgad, Tomás García. *Anamorphic Perspective & Illusory Architecture.* 2003. http://www.generativeart.com/salgado/anamorphic.htm (accessed February 2018).
22. In *Performative Architecture: Beyond Instrumentality*, by Branko Kolarevic, & Ali Malkawi. New York, London: Spoon Press, 2005.
23. Mennan, Zeynep. "Mind the Gap: Reconciling Formalism and Intuitionism in Computational Design Research." *Footprint, Delft Architecture Theory Journal* 15 (2014): 33-42.

CHAPTER TWENTY-THREE

COMPLEX BUILDINGS AND CELLULAR AUTOMATA: A CELLULAR AUTOMATON MODEL FOR THE *CENTQUATRE-PARIS*[(1)]

ROBERTO D'AUTILIA, JANET HETMAN

Introduction

In a memorable essay addressed to biologists, John von Neumann describes the structure of an automaton which reproduces itself, even in a more complex or evolved form, thus illustrating the logic that serves as a deciding principle for living beings and computers.[1] Numerous results have emerged from these ideas, showing the way a simple local rule can produce a complex global behaviour. This is the main idea behind the theory of cellular automaton.

These concepts have been widely applied in different fields, from statistical mechanics to traffic analysis to models of artificial intelligence. This paradigm led to a large range of results and methods that nowadays are used to model and understand complex collective phenomena. In addition, the increasing speed of computers during the last decades has allowed to simulate the dynamics of the structures formed by many interacting subparts in an efficient and realistic way. While at the same time some formal methods of analysis, often derived from other disciplines, have been widely used in urban planning.[2] Finally, on a smaller scale, like the architectural one, the same methods seem to have been incorporated with greater difficulty[3]. If the large numbers of urban sizes suggest probabilistic analysis

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naturally, it is apparently more difficult to find similar numbers in the behaviour of a single building. In fact, in the case of a single building probabilistic analysis have been applied to shaping architectures in formal fields with a generative project.[4, 5] Furthermore, a large part of the functional programs in architecture are realised by distributing spaces and activities with the aim to optimising surfaces, resources and use effort, even in complex buildings type.

The increase in complexity at the architectural scale is well expressed by recent history, revealing how buildings, located in a dense urban environment, have been designed to allocate and accommodate multiple uses in a space-time program. Architecture has recently dealt with this problem in interventions of mixed socio-artistic-cultural buildings.

The well-known design experiences of the Fun Palace by Cedric Price, the Parc de la Villette (that embodies the Event-City) by Bernard Tschumi, and the Centre Pompidou by Renzo Piano and Richard Rogers,[6, 7, 8] identify a family of buildings that today are known as Complex Buildings.[9]

While the city has witnessed a proliferation of practices[10], buildings have accommodated a multiplication of uses. The increase observed at the architectural scale, converts these types of buildings into Incubators of uses, where the complexity deals in the multitude of configurations with different uses, actors, users, equipment, etc. The consequences are an increase in the number of variables and a development of a new forms of management, transforming buildings into intelligent systems that meet the dwelling needs of the contemporary city, associated with that proliferation of uses and agencies.

From this point of view, buildings have to be programmed to guarantee a good cohabitation between its different uses. In fact, the management has to be able to arrange the uses in spatio-temporal configurations (programming) in which the main goal is to preserve the compatibility between all the parts.[11] Basically, a well-made configuration can affect public participation and consequently to increase the economic value of the building.

This paper aims at proposing a descriptive mathematical model to show how it can represent an effective government tool for a Complex Building.

Case Study, Methods, and Data

The *Centquatre, établissement artistique et culturel* located in the 19th arrondissement of the city of Paris is the French case study chosen to explore the hypothesis. As a part of the French political program of decentralization of culture, in 2008 the city of Paris transformed a nineteenth-century public building of the funeral home[12] into a cultural centre. Formally, the *Centquatre* is an EPCC (*établissement public de cooperation culturel*) which enables the direction to build partnerships with other public or private entities for cultural, artistic, and social purposes.[13]

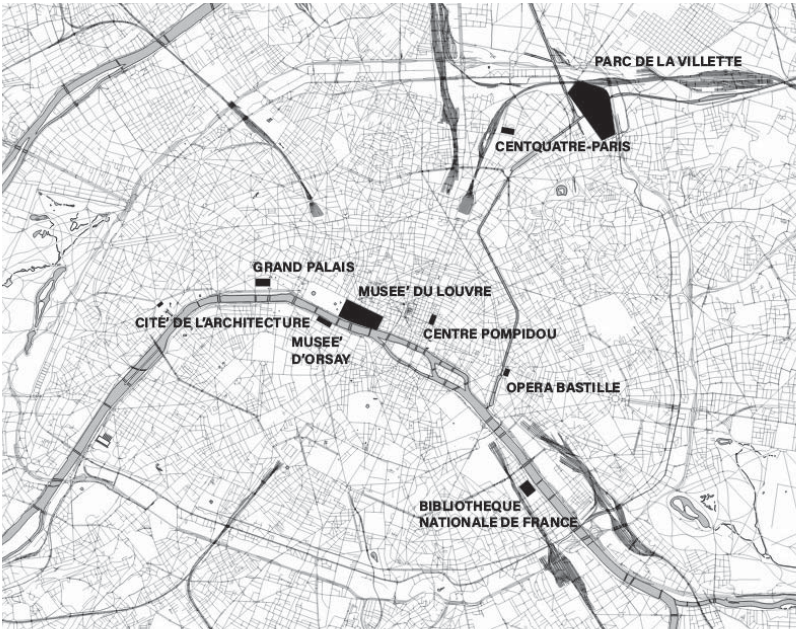

Figure 23.1

Map of the main public artistic and cultural centres in the city of Paris.

Its main activities include free social activities aimed at the inhabitants of the neighbourhood (the target includes both adults and children), artistic activities of production and representation of shows and exhibitions, commercial and productive activities (shops and restaurants, star-up incubator, an architectural, urban planning and cultural engineering consultancy service). Each of these activities addresses, and therefore attracts, very different persons. Consequently, the *Centquatre*'s population is a mix of residents of the district, citizens from the city centre or from the suburbs, artists and users of artistic activities, or creatives hosted in the factory and among others. In this way the institute get a variety of public that *reproduce the world*, as expressed by Jean Bourbon, direction des publics. The case study has been chosen because it is highly innovative, involving up to 12 categories of activities in the program, and attracting a high number of visitors (about 5000 people per day). The importance of these figures is further supported by the growing budget for the *Centquatre* over the last two years (+25% on a budget of €16 million per year). In addition to the management's skills, the architectural configuration helps to obtain these numbers, basically because of the main central space configured and used as a public space.

The paper uses a mixed method approach, in which quantitative and qualitative tools are used in a productive, integrative way.[14] As a matter of fact, the cellular automata experimentation presented here would not have been possible without the knowledge gained through the ethnography the collection of qualitative data involved 6 months of participant observation, unstructured interviews and a field survey. In order to make qualitative data suitable for the calculation with cellular automata, the daily tabs of programming and reports were represented into quantitative categories.

The Centquatre-Paris

In order to understand better the complex phenomena of the *Centquatre*, we start by describing this building as an incubator of uses, and how the different elements relate to each other.

To begin with, we propose two descriptions made by the main managers: Christophe Girard, president of the *Centquatre* board of directors and promoter of the project as councillor for culture at the time of the rehabilitation; and by José-Manuel Goncalvès sociologist and the artistic director of the *Centquatre*.

Christophe Girard defines the institute as a collaborative artistic platform in which art is made accessible thanks to a popular, yet contemporary and committed, program. For him, the *Centquatre* is an *aesthetic refuge where art, society and innovation meet*, and where there are *multidisciplinary arts, public mixite, diversity of activities between art and innovation, commerce and public interest. The links between these activities allow for almost infinite* combinations.[15] On the other hand, José-Manuel Goncalvès emphasises that the institute's goal is to be a place *of experimentation, rather than model, where the primary interest is aimed at doing* together.[16] The "experimentation on the links" between the different activities guarantees that the *Centquatre* is conceived, managed and used as an "open place", a space available to individual and collective appropriations, and in which subjects, actors and activities are in a dynamic relation. Therefore, the institute committees to carry out simultaneous actions at different levels, and in an integrated way:

- social: LeCinq, La Maison de Petits e Public Space ;
- artistic: shows, concerts, exhibitions, activities;
- mediation with the public;
- production and innovation: performing arts, bringing out artistic activities from the non-expert public, sturt-up of the Factory, consultancy service;
- management: planning, relationships with sponsors and customers;
- commerce: restaurants, retailing, space's privatisation for external events.

The set of actors, activities and spaces shows how many possibilities of interaction the *Centquatre* offers to its users and to the city, offering an attractive program for the people, which in turn work as the platform whereby all the components are determined.

The institute and its spaces are attractive thanks to the program. It turns out to be the determining component with which the configurations are determined. In fact, the activities are organised on the basis of the envelope, the furnishing and the term of each event. In addition to its own activities, the *Centquatre* also hosts external events, offering the possibility to rent their spaces for private events (fashion showrooms, conventions, catering, etc.). On one hand this availability has a considerable economic impact, and on the other it allows attracting people and uses that are generally far from the usual activities.

The activities do not have a foreseeable recurrence. On the contrary, they are deeply uncertain and this requires a weekly definition of the program. The deep degree of uncertainty makes the direction to set up different configurations whereby activities are organised according to their compatibility. For this reason, the *Centquatre* can be considered a complex dynamic machine in process, as *open places. Places that reinvent themselves with each new* initiative.[17] Such plurality of uses is possible thanks to an architecture that has been particularly designed to meet this goal. In fact, the rehabilitation was the result of a French procedure named *marché de* definition,[18] in which the functional program and the architectural requirements were defined simultaneously. Usually applied to large urban areas, this procedure allowed to configure the space in order to widen up the possibilities of the building thanks to the large central space. And in this sort-of-yard, used as a public space, different configurations of activities taking place at the same time are visible. Each configuration has a different ability to attract a particular public, and it is there, in this pseudo-public space, where all the people participating in any given activity are concentrated. Thus, this place becomes, like an urban public space, the place for nurturing and building up relationships. The participation of the public to the events taking place in the public space is the resource called by the *Centquatre*. In fact, the aim of the direction is to multiply the physical presence of the people in the public space thus generating more value.

In this paper, we discuss that value added by the physical presence of people in the space, and therefore how the public space is the real resource of the institute. From this point of view, the architectural space represents the basic support to this mechanism. It guarantees the simultaneous and integrated development of the various activities, which are distributed within the 39000 square meters of the building. Specifically, the central yard, activated as a public space, plays a paramount role to fulfil the operation described above.

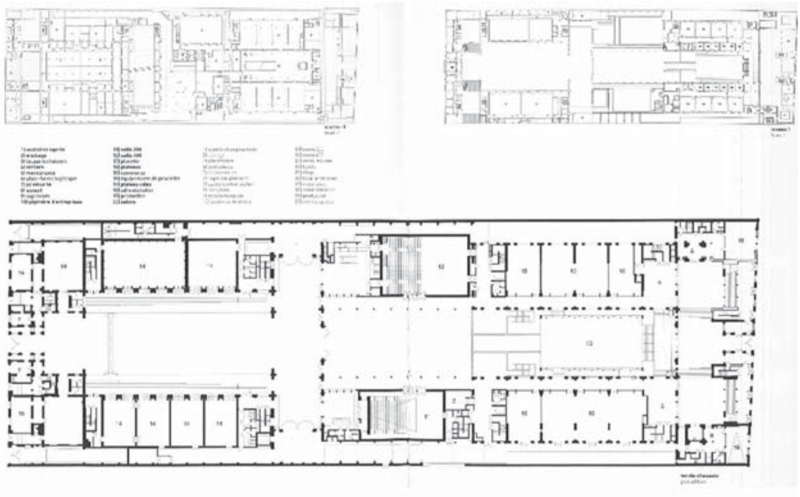

Figure 23.2

Architectural project.

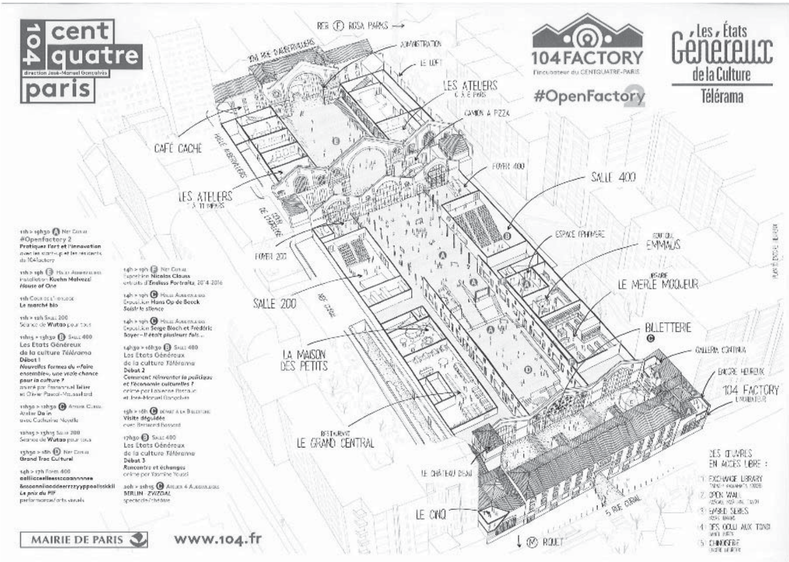

Figure 23.3

Complexity of the *Centquatre*.

Description of the Data

As discussed before, in order to describe the configurations of uses and the role of public space, we used a mixed methods approach. On the one hand, the ethnographic analysis has allowed the acquisition of an empirical knowledge that facilitates the comprehension of the phenomena and guarantees the reading of the data collected in the field: in particular the daily planning schedules (Figure 23.4). This qualitative data allowed the construction of the chronocarta, an experimental dynamic map of a Complex Building in its space-time component[19] (Figure 23.5). In addition, the direction of the institute collects the daily inflows of the public to the activities of the program into daily report (Figure 23.6). These to different data sources have been treated and prepared for the calculation process with cellular automata.

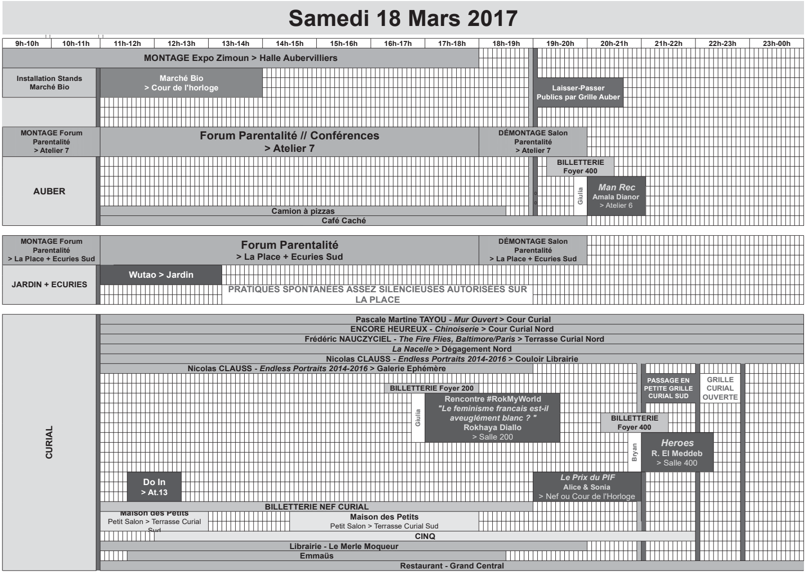

Figure 23.4

Planning sheet in use by the direction and referred to 18 March 2017.

Figure 23.5

Frame of the Chronocarta of 27 February 2017, between 5:00pm and 6:00pm.

From: Manuel TOMICHE
Sent: venerdì 3 febbraio 2017 1.21
To: bilan
Subject: Bilan du jeudi 2 février 2017

Bonsoir,

Les chiffres du jour :

- La Chinoiserie : environ **70**
- Nicolas Clauss : environ **120**
- Il était plusieurs fois : **96** (chiffre billetterie)
  - Loft : 152
  - Château d'eau : 74
- Circulation(s) : **209** (chiffre billetterie)
  - Atelier 0 : 125
  - Atelier 2 : 207
  - Ateliers 1, 3, 5 : 213
  - Halle Aubervilliers : 249
  - Little Circulation(s) : 180
- Les Illuminations : **37**
- Bambi dans la jungle + Tous les hommes sont des Vampires : **91**
- La Maison Tellier : **749**

Figure 23.6

Daily report of 3 February 2017.

The data collected for this paper was provided by the board of the *Centquatre* during the 6 months that the ethnography lasted from October 2016 to March 2017. A fundamental step using a mixed-method approach was to select and edit the data with different origin, difference that required a selecting and editing work to make them homogeneous and valid over a continuous period of time.

Data coming from three sources:

- the online program which mainly includes the "*que faire au 104*", activities and events accessible to the public. Often offered in free form;
- the data of the internal planning of the *Centquatre* in which there are the spatialised events (both the assembly and the development of the event itself);
- the daily reports collected by the direction, describing the status of the activities and the number people participating.

To further optimise the analysis, the selection of data and the calculation refers exclusively to the configurations during the months of February and March 2017, for this period contains data with the strongest continuity and homogeneity. Even if during one week we were not able to gather daily reports, we estimated and reconstructed the missing data to allow for the quantitative analysis.

The data was summarised and coded during the transcription process; it aimed to describe the configurations of each active hour for a single day numerically. A total 53 days are analysed, with an average of 11 hours per day. This resulted in 583 real configurations, from which the most significant configurations for each day were extracted and further analysed. Therefore, the calculation carried out shows 10% of the volume of data gathered.

The program data is differentiated sheets for each day and, as shown in Figure 23.4, these sheets contain the information of the activities allocated by temporal extension and their spatial envelope. The activities are differentiated by colour bands on which the name of the activity and further details on the specific location are inserted. In order to make the planning scheme more comprehensible, the *Centquatre* chronocarta was drawn up. It simplifies the reading of the elements and lets the dynamism of the configurations in the space-time flow emerge.

In relation to the daily reports, these included:

- number of turnouts to the shows. This number refers to the specific activity and it is overall considered for the day and the specific space section;
- number of participants in free activities accessible to the public. The figure sometimes refers to the specific activity and sometimes to all the activities. Also, in this case the total refers to the day and is specific for the space section;
- number of people present on the public space. The figure refers to all the spontaneous practices present in the public space. In this case, the reference figure is counted on the week with the distinction between weekdays and weekends. Moreover, it does not specify a spatial section, but the surface of public space made available, which is not regular.

The analysed period captures the extent of the activities taking place in the institute. It should be noted that on Monday, although there may be activities in progress, it is a day of closure to the public. For this reason, the collection of daily data on the use of the structure is not envisaged, and the value of the configurations on Monday will predominantly have a negative value. In parallel to the homogeneous data editing, the building has been drawn down in a simplified way.

Description of the Procedure

The simulations presented in this paper were carried out through the analytical tool of Mathematica 11.2 software. The starting model is the cellular automaton. The building is seen as a set of cells, each of which can be in the state corresponding to its purpose. There are 12 possible purposes:

1. service/ticket;
2. proximity services;
3. commercial activities;
4. exhibitions;
5. shows;
6. groups;
7. inaccessible activities (maintenance);
8. private events;
9. partnership;
10. internal visits/meetings/activities;
11. public space/spontaneous practices;
12. toilet/connective facilities (stairs, elevators)/secondary corridors;

The institute's spaces are divided in 67 areas. If each of them is in one of the 12 possible states, the number of possible configurations of purpose for the centre is 1267, which is a gigantic number, namely the order of 1072. Of course, not all areas can have all the functions, but the number of configurations targeted, even if reduced, remains large enough to justify a statistical treatment.

It must be added that in the case of cellular automaton, there is the rule that the change of state of a cell is influenced by the nearby cells. In our case, the modification of the state of an area depends, in line with the principle, from the state of all other areas. Some of these dependencies will be very strong, some weak, some still even conflicting, but at this moment, it is not known how this complex network of relationships is structured. However, it is known that a reward is associated for each configuration of real purpose of *Centquatre*; a score, for example the number of visitors or an economic revenue.

Based on the available information, the actual configurations and the corresponding rewards, we wanted to estimate the network of relationships that binds the individual areas. From this estimate, we calculated the possible reward of a configuration not yet tested.

As a reward for a configuration, we choose the number of people who visit the building in that condition. Of course, this number could depend on many other variables, weather, advertising, a specific attraction of a space of the building. However, we were constructing a statistical model and therefore assumed that on large numbers these variables are mixed in a sort of randomness, partly determining the probabilistic nature.

We divided the *Centquatre* area into 352 subareas squares by superimposing a square lattice of dimension 3211 and attach to each square a colour and a numerical code corresponding to its function according to the following table:

Service / Ticket	1	
Proximity services	2	
Commercial activities	3	
Exhibitions	4	
Shows	5	
Groupes	6	
Inaccessible activities	7	
Private events	8	
Partnership	9	
Internal visits / meetings / activities	10	
Public Space / Ppontaneous practices	11	
Toilet / Connective facilities	12	

Table 23.1

Configurations with the corresponding number of visitors.

In this way, each configuration of purpose of *Centquatre* can be represented graphically. The following figure shows examples of 16 real configurations with the corresponding number of visitors.

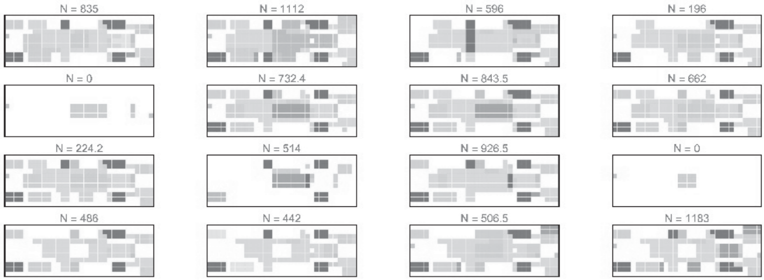

Figure 23.7

Configurations with the corresponding number of visitors.

To estimate how the different purposes are correlated with each other and how to correlate with the number of visitors, we exploit four possible models of Machine Learning: Linear Regression, Nearest Neighbours, Neural Network and Random Forest. The goal is to understand which model is the most reliable. For the details of the description of the functioning of these models, we refer to the numerous literatures on this topic.[20, 21]

We trained the four Machine Learning models to associate fifty real *Centquatre* configurations to the corresponding number of visitors and then used the predictors, obtained to predict the number of visitors for the following 6 real configurations.

Figure 23.8

Prediction of the number of visitors.

The number of visitors expected from the four models for these configurations are shown in the following table:

						
Real	286	272	713	181.5	262	171
Linear Regression	2.37459×10^9	-4.11057×10^9	-4.39519×10^9	2.68071×10^9	2.76964×10^9	2.011×10^9
Nearest Neighbors	447.505	473.325	473.325	466.905	520.105	546.51
Neural Networks	86.4512	263.873	184.793	-81.7465	331.432	-33.4817
Random Forest	288.083	377.677	377.677	184.083	184.083	358.964

Table 23.2

Prediction of the number of visitors.

As shown in the tables, the most reliable model is the Random Forest, even if the numbers are still too far from the real ones. However, this discrepancy is due to the limited number of samples, as described in the training parameters table.

Predictor information	
Input type	Image
Method	RandomForest
Standard deviation	$757. \pm 2.0 \times 10^2$
Loss	8.39 ± 0.68
Evaluation time	61.8 μs/example
Predictor memory	116. kB
Training examples used	50 examples
Training time	26.8 s

Table 23.3

Predictor Information.

Results

The predictors have been trained to “learn” the images with the informative content linked to the spatial dispositions of the purposes. By training the predictors on the vector representation of the configurations, for example by representing states as an array of numbers, we get poor results with almost all the predictors. The failure of the Linear Regression shows that the behaviour of the automaton is deeply non-linear: a very small change in state can cause a big change in the number of visitors, whereas the Random Forest model seems to capture this non-linearity better than the other predictors. The dataset is in fact analysed as a set of weakly correlated subsets based on different characteristics. The result is a sort of average on multiple decision trees, in the machine learning sense. The real states classify the spaces by means of the number of visitors as in the following dendrogram.

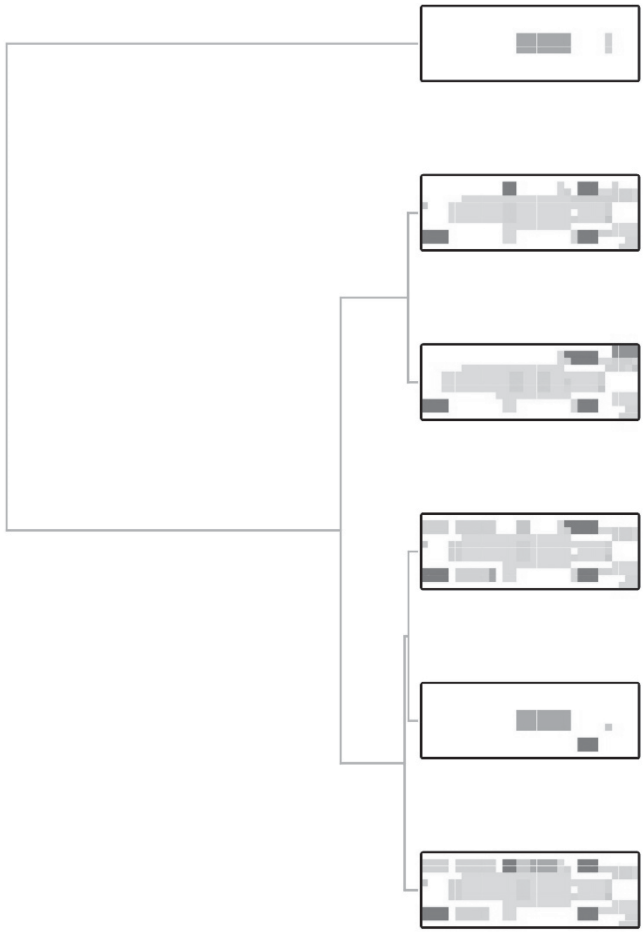

Figure 23.9

Real case.

While the Random Forest partition is the following, apparently more realistic one.

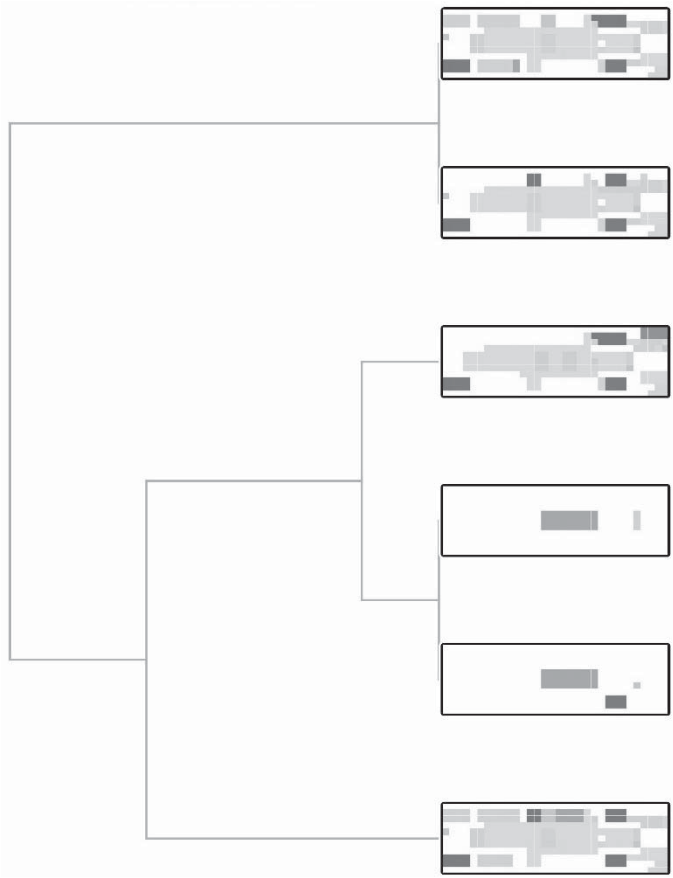

Figure 23.10

Random Forest.

It is possible to indicate that the simulation carried out, together with the data processing process has led to the identification in the Random Forest of an effective method. It is precisely from this point of view that the statistical treatment applied to the scale of the building is not only possible, but it is also foreseeable an increasing application in the years to come at least in the type of buildings observed.

Discussion

The overall result indicates that the modelling of *Centquatre* as a cellular automaton, together with the search for the rules of the automaton by means of the tools of Machine Learning, seems a very promising way to build up an instrument for economic planning. By monitoring the building continuously and collecting data on social and economic purpose and responses, the predictor is able to provide increasingly precise answers.

The predictions of the 109-order provided by the linear model, show that the behaviour of a Complex Building is not adequately represented by a simple proportionality between causes and effects. In addition, while some spatially distant activities may influence each other, the Nearest Neighbours models appear to be unsuitable. Finally, the unrealistic negative values returned by the Neural Networks are probably a size effect which disappear with the increase of the input data. The Random Forest method seems the most reliable method mapping efficiently different structured choices.

The results achieved with a small number of data are very encouraging, suggesting deepening the approach by using more extensive and robust data. The selection of an optimal model, although it requires more in-depth analysis to explain the failure of some models, suggests that the Random Forests represent an effective tool for evaluating the management of a Complex Building.

It should be emphasised that a predictor is only an instrument for the measurement of does not replace the planning of the use of spaces, which must be made on the basis of choices that take into account many variables. It should be noted that the 12 purposes we have considered can be further refined by going into details of the single activity. Within the limits of the available computational capabilities this refinement should provide much more precise and reliable predictions. Finally, it is possible to observe that, as in the case of *Centquatre*, behaviour coding may also be required in other Complex Buildings. Obviously, in those cases where the activities are multiple and concurrent for which compatibility must be ensured.

Conclusions

Building on the results discussed in the previous sections, we state that the complexity found at the architecture scale of the *Centquatre* is proper of cities complexity. In fact, we can make a step further to recognise our selected case study as a well-designed Complex Building because of the *marché de definition* process and because of its architectural solutions. For this particular case, we discuss how the French approach has revolved around prefiguring a functional and spatial program to a single building, that is, aiming at transforming it into an incubator of uses. In other words, revealing a relevant degree of complexity, an urban one, within a single architecture. Further, we identified two dimensions that can help or allow this process. First, the application of big data mining techniques to a building. And second, the essential value of the indoor public space.

In fact, from one hand the behaviour of a Complex Building can be described as a cellular automaton, and therefore be analysed through machine learning techniques. In fact, the behaviour of a Complex Building, as an incubator of uses like the *Centquatre*, can give rise to a variety of situations so numerous and varied that it is necessary to use big data mining techniques, in particular those that exploit artificial intelligence. As the results indicate, this approach is viable with an appropriate classification model, as the Random Forests in addition to a sufficiently large and robust data set. On the other hand, the work here shows how a Complexity Building is the result of the integration of the public space within the architecture. As illustrated by the *Centquatre*, the large central area assigned as public space is the spatial component in which activities and uses are distributed in configurations (some examples in Figure 23.7). Accordingly, this is the reason why the indoor public space is the paramount place where the *Centquatre*'s visitors are mostly present at the same time. The relationship between the uses, included in each configuration, and the number of visitors, participating to the several uses, is explored in the paper as a non-linear system, and it is analysed through the Random Forest. Furthermore, this relationship shows how the people's presence in the indoor public space represents a social and economic value. The highly presence of diverse public in the same space performing different activities reveals a form of inhabiting proper of the urban public space because it generates encounters and conviviality, even if within an architectural space. This dimension describes that the ordinary public life is incorporated inside of a building, which is an organised system with a specific goal. Therefore, according to the system's goal, the people's presence can be used as economic value, as the *Centquatre* does.

References

1. von Neumann, J. and Taub, A.H. *Collected works*, no. v. 1, Pergamon Press, 1961.
2. Batty, Michael, *The New Science of Cities*. The MIT Press, 2013.
3. Batty, Michael, Carvalho, Rui, Hudson-Smith, R., Milton, Richard, Smith, Duncan, and Steadman, Philip. *Scaling and allometry in the building geometries of greater London*. C.A.S.A. working paper 126. https://www.ucl.ac.uk/bartlett/casa/case-studies/2007/dec/casa-working-paper-126 (accessed 25/01/2018).
4. Herr, C.M., Kvan, T. (2005) Using Cellular Automata to Generate High-Density Building Form. In: Martens B., Brown A. (eds) *Computer Aided Architectural Design Futures 2005*. Springer, Dordrecht.
5. Krawczyk, R. (1997) Programs as Pencils: Investigating Form Generation, *ACADIA 1997 Conference, Association for Computer-Aided Design in Architecture.*
6. Price, C. (2003). *Cedric Price: the square book*. West Sussex: Academy Editions.
7. Tschumi, B. (1994). *Architecture and disjunction* (MIT Press). Cambridge.
8. Piano, R., Rogers, R., & Picon, A. (1987). *Du Plateau Beaubourg au Centre Georges Pompidou: Renzo Piano, Richard Rogers / entretien avec Antoine Picon* (Ed. du Cen). Paris: Paris Association des Amis du Centre Pompidou.
9. a+t research group. (2017). Complex Buildings. Generators, Linkers, Mixers & Storytellers. *Issue 48*.
10. Crosta, P. L. (2010). *Pratiche. Il territorio "è l'uso che se ne fa."* Milano: FrancoAngeli.
11. Weick, K. E. (1998). Improvisation as a mindset for organizational analysis. *Organization Science*, *9* (Jazz improvisation and organizing), 543–555.
12. Bertherat, B., & Chevandier, C. (2008). *Paris dernier voyage. Histoire des pompes funèbre*. Paris: Éditions La Découverte.
13. Atelier Novembre. (2009). *104. Reconversion des anciennes pompes funèbres de Paris en centre de création artistique, le 104.* (Archives d'Architecture Moderne, Ed.). Bruxelles.
14. Corbetta, P. (2003). *La ricerca sociale: metodologia e tecniche. I. Vol. 1: I paradigmi di riferimento.* Bologna: Il Mulino.
15. 104 Centquatre-Paris. (2015). *Bilan d'activité 2015*. Paris.

16. Ibid.
17. Ibid.
18. DIV Délégation Interministérielle à la Ville, & DGUHC Direction Générale de l'Urbanisme de l'Habitat et de la Contruction. (2002). *Marchés de définition une démarche de projet urbain*. Paris: les éditions de la DIV.
19. Guez, A. (2010). "L'entre-temps": una postura di progetto. In *La città e il Tempo: interpretazione e azione* (Maggioli, pp. 309–313). Milano.
20. Ian Goodfellow, Yoshua Bengio, and Aaron Courville. *Deep Learning*. The MIT Press, 2016.
21. Kevin P. Murphy. *Machine Learning: A Probabilistic Perspective*. The MIT Press, 2012.

CHAPTER TWENTY-FOUR

MADE BY ARCHITECTS, MODIFIED BY PEOPLE: A GRAMMAR FOR USER INTERVENTIONS

AMINA REZOUG

Introduction

In the 1950s, an intense housing program was executed by the French rule in Algeria for indigene people. Today, most of these housing complexes have a reputation for decrepit and secluded conditions. Fernand Pouillon was the master architect of that period and had three major housing complexes constructed in Algiers. *Climat de France*, one of his monumental and massive housing ensembles designed in Algiers is today in a very different state from its original design. Residents of the ensemble have highly modified the blocks according to their needs. Designed as indigenous housing complex, the apartments have tiny sanitary facilities and minimal spatial requirements. Today, still occupied by the same residents, the apartments lack the ability to satisfy their basic necessities. As a solution, residents generated their own local interventions.

This study aims to analyse these reappropriations through shape grammar, by integrating their problems such as need of shade, light, space or ease to clean with formal rules applied to transform the original design. The size of intervention, the material choice and the building technology chosen by the residents carries information related to its context. One of the questions this study deals with is the possibility of using shape grammar in order to represent not only architectural style but also user identity and cultural context. Regarding the descriptive nature and generalisability of the grammar, analysis of social, cultural, and economic aspects of the user and built environment can increase its potential by adding value to its formalism.

The application of shape grammar on the analysis of an existing building modified by its residents, questioning the possibility of analysing residents' need using shape grammar and questions a grammar's ability to generate context-adapted solutions is the focus of this paper. First of all, the architecture of Fernand Pouillon is analysed, and an analytical grammar of the 200 columns block is investigated. This research would proceed by identifying the residents' interventions and determine the motive behind them. Then, the spatial and constructive transformations would be identified as formal rules of these motives. Finally, a basic composition including the original design and the user interventions will be proposed.

Background

The theory of shape grammars, first introduced by Stiny and Gips in 1972,[1] is a computational design method used to analyse and synthesise designs by embedding and calculating shapes with a set of rules. Shape Grammars dealing with architecture subdivides into analytical and original shape grammar[3]. The first grammar was developed for the Palladian Villas[14], which can be categorised as an example of analytical grammar. Original grammars, on the other hand, are the one developed within the design process. They are products of new and original styles. Malagueira housing[3] is an original shape grammar that benefits from the architect Alvaro Siza's support.

Duarte *et al*.[4] studied the Marrakech Medina and develops a parametric shape grammar able to capture its architectural and morphological characteristics. In this study, they conduct a fieldwork to identify the urban pre-existence and encode three sub-grammars: the urban grammar, the negotiation grammar and the housing grammar. The grammars are differentiated according to their scales and applied in both bottom up and top bottom approaches. Another study[5] focusing on the Mozambican Slums, uses shape grammar for analysing the evolution of Maputo's slums with the strategic objective of capturing the evolution of house types and understanding the social agreement behind the spatial relations of these houses, in order to reuse similar rules for the purpose of rehabilitation. What distinguish the Mozambican Slums study from the Marrakech Medina study is the focus on the evaluative aspect of design and generating a grammar for it. However, both of these studies focus on a single vernacular style and seek a method to identify and improve it.

In the case of this research, there is on one hand the existing design created by the architect and on the other the residents' interventions that mould it into their homes. This study regards these two methods of making as mutual but different styles. According to Benros *et al*.[6] a grammar can describe more than one style, as they investigate a generic shape grammar for the

Palladian Villa, Malagueira House and Prairie House. In their research, they establish a grammar that describes more than one style, yet each grammar works separately. The question that this study deals with is the possibility to develop an original grammar that describes and execute different styles mutually, in order to achieve a resident controlled, existing housing rehabilitation strategy.

Made by an Architect

The architecture of Fernand Pouillon consists of repetitions of strong orthogonal geometries. The style of the architect can be depicted from the repetitive layout visible on the facade of his buildings. The superblock so called the 200 colonnes is a monumental block surrounding a large opening with the same size as the Palais Royal in Paris. The architect's ambition was to introduce monumentality to everyday life of the poorest of Algeria. The 261m long, 66m width superblock consists of 57 blocks of 6 different types. The repetitions of the blocks on a 261m facade create a repetitive pattern. There are three kinds of openings, 90x100cm plus 90x33cm opening for each room (opening 1), 33x33cm square opening on the staircases (opening 2), and the upper floor narrow window (opening 3). The façade opening is reflected on each floor in order to break monotony and achieve an appealing facade pattern with the only three types of openings (Figure 24.1).

The plan of the 200 columns consists of the juxtaposition of two different grids, the 100x100cm grid that localise the columns. Another grid of 60x60cm originates from the size of each waffle on the slab. All interior partitions and apartment layouts are organised according to this second grid. However, the façade articulation has no direct relation with the 60x60cm grid neither the layout of the apartments. Each room has an opening however the location of the opening is detached from the interior organisation. On the other hand, the façade openings are related with the 100x100 grid and the location of the columns (Figure 24.2). It is obvious that Pouillon treated the façade and the plan layout separately. Regarding the tight spatial organisation of these apartments and the complicated ideology laying behind the conception of this project, it is not hard to understand the motivation and need of the current inhabitants of this superblock that lead them to make adaptations. Reappropriation seems to be the strongest tool of the resident of *Climat de France* to express themselves and fulfil their spatial needs.

Figure 24.1

The three types of openings on the outer façade of *Climat de France* (source: Archive of Association Pierres Sauvages).

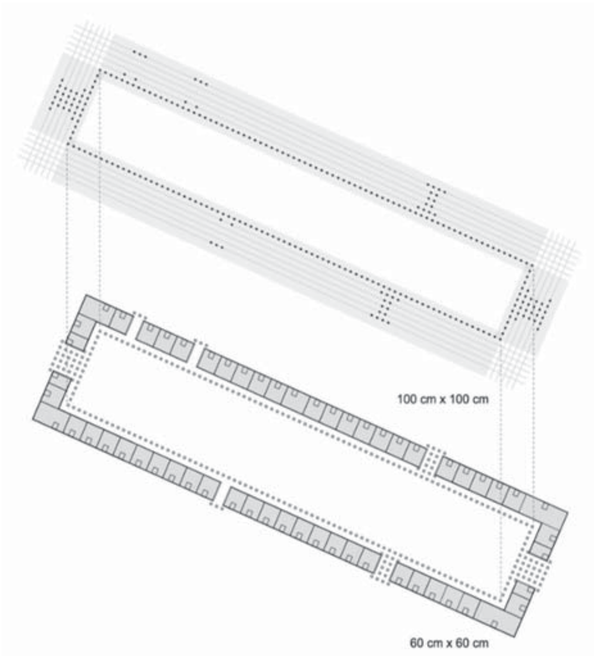

Figure 24.2

60x60 grid that regulates plan layout and the 100x100 grid assigned to columns and façade configuration.

Modified by People

The material culture of the home deals with the changing social relationship of its inhabitants, questioning the complexities, conflicts and compromises involved in creating a home. In the case of mass housing inhabitants have restricted opportunities of creating their home, in reference to Habraken *they have limited control to their environment*[7]. However, in the case of *Climat de France*, the inhabitant interventions may be identified as resistance acts relying based on Hooks' argument that "home-place" can be a site of resistance[8] against the government, the society, and the architect. Reappropriations are tools of self-expression of their makers. Miller defines the processes by which dwellings are personalised through concepts such as appropriation and accommodation.[9]

An inhabitant's control over the place he/she occupies is essential and it is the main problem with mass housing according to Habraken.[10] Dwelling as a part of the built environment is defined by the act of settlement. He adds that by realising this act of settlement we all turn into players, agents who inhabit the environment, transforming it to our liking and making sure things stay as we choose, within the territory we claim. He introduces levels of control and categories nine modes of dwelling through these control levels. Body & utensils is the first level of control, furniture the second, partitioning the third, building elements as the structural frame of the building the fourth, the roads the fifth and major arteries are the sixth level of control. The higher the control level is, the more difficult it is to transform. Majorly inhabitants of mid-class have control over the second and in rare cases over the third level.

Mass housing reduces the dwelling to a consumer article and the dweller to consumer[10] the inhabitant has no control over the process. *In order to regain control over our housing we must rediscover what has been lost through a long preoccupation with mass housing*, he includes. This prospect of regaining control is visible on the façades, rooftops, and ground floors of *Climat de France*. Home re-appropriation is at fourth even the fifth in some cases, control level.[7] The concept of home accommodating through different control levels is used to structure the user interventions and transmit them into a re-appropriation grammar.

User Interventions

Intervention Levels

The re-appropriation released by the resident of *Climat de France*, are grouped under three levels. The first level is the most impertinent one which is extensions based on existing walls and slabs. The second level is the most commonly practiced re-appropriation method, modification of façade openings. The third and last level consist of the loose interventions realised by attaching elements such as fences and curtains and other shading elements to the façades. Each of these levels points out to specific spatial requirements and needs such as lack of space, practicality, light and air control, privacy and safety. However, most of the time each intervention points out to more than one need.

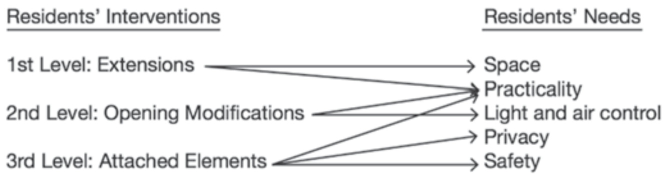

Figure 24.3

Resident interventions, residents' needs and their relation.

In order to translate these interventions into a reappropriation grammar, a bottom up approach of their making process is adopted. Differently than the existing design grammars that have been successful in analysing style and designs, we address a context driven user intervention to design in the grammars for the *Climat de France*. Resident interventions are problematised in reference to Knight and Stiny's knotting grammar[2] in which they adapt shape grammars for computing shapes to making grammars for computing things. Based on initial analysis, the process of making and doing in residents' interventions is more a shared one, built upon a collective knowledge and local practice, and less of individual creative decisions. As Ingold[11] explains, form is a result of something; thought processes and motivation materialise the form. In analysing the formal transformations of the facades, it may be possible to understand the thought, motivations, and constraints through a backwards read of their making process. Shape computations are now *more than ever regarded as a kind of making activity: the basic spatial elements are the materials for making and the shapes computed are the things* made.[2]

Algebra for "stuff" needs to capture the sensory and experiential properties of stuff that are pertinent to making.[2] Based on algebra for stuff, a reappropriation grammar for computing user-oriented adaptation is introduced through doing. The proposed grammar includes things (1st, 2nd and 3rd Level reappropriation), stuff (walls, slabs, façade openings or façade and walls), doing (breaking, redefining, fixing and repairing) and sensing (Residents' needs: practicality, light and air control, privacy, safety, lack of space).

Things	1st Level of Reappropriation
Stuff	walls, slabs
Doing	tools and competences (breaking, redefining, fixing, repairing)
Sensing	practicality, lack of space

Things	2nd Level of Reappropriation
Stuff	façade openings
Doing	tools and competences (breaking, redefining, fixing, repairing)
Sensing	practicality, light and air control, privacy

Things	3rd Level of Reappropriation
Stuff	façade, walls
Doing	tools and competences (fixing)
Sensing	Practicality, light and air control, privacy, safety

Figure 24.4

Developing the three reappropriation levels in reference to terms of the knotting grammar.

Reappropriation Grammar

The architecture of Fernand Pouillon treats the façade and the plan layout separately in the case of Climat de France. The 2nd and 3rd levels of re-appropriation are directly related to the façade modification. Their grammar would be developed through two-dimensional façade representations. The 1st level of reappropriation is related to the plan as well as the facade of the existing building. Therefore, it is represented on both levels. The grammar consists of things, stuff, doing and sensing.

First of all, the doing rules are defined in relation to the process of re-appropriation, and the actions that shape it. What identify these rules are the basic actions required for any kind of constructional accommodating that change the outer appearance of the building. There can be no change without removing the existent opening/wall, replacing them by the new one and adjusting it. Secondly, the stuff that are introduced are walls, slabs and façade openings. And finally, the doing rules that generate re-appropriations are defined, breaking, redefining, fixing and repairing. Making is a continuous, time-based process[2]. The grammar of reappropriation holds the continuous tense (-ing) as a constant reminder that the computation of these rules can only represent one of many possible resident interventions in a very specific timeframe.

1st Level of Appropriation

Extensions made by residents of *Climat de France* are located either on the ground floor or the rooftops. These two-different types of extensions are generated differently, since one is attached to the walls of the building while the other is built on the top floor slab and is shaped in relation to the existing rooms. Walls are defined as things and represented as 2D drawings in all kind of extensions. The inner components of the extensions such as the wall, window and door are defined as stuff. The doing rules are grouped under four main actions that generate user interventions with the things and stuff mentioned previously.

Ground floor extensions:

Extensions created on the ground floor are independent rooms attached to the walls of existing buildings. The size and material used in the creation of these rooms depends on residents' taste and competences. Windows on the façade are removed, their opening is redefined according to the extension needs and walls are constructed surrounding the planned area to create the extension. The extensions are located within the boundaries of the apartment they belong to, without blocking openings of their neighbouring apartments. In Figure 24.5 the doing rules of a ground floor extension are demonstrated, breaking, redefining, placing and repairing. The break rule represents the process of removing the existing façade opening. The second rule is redefining the opening in the façade in order to enlarge the room. The third rule is placing/ fixing the walls of the extension and the final rule is repairing, which includes all kind of finishing applied in order to finalise the extension.

Rooftop Extensions:

Extensions on the rooftop are located according to the staircase and laundry room designed by Pouillon on each rooftop. In most cases they are shared by neighbours, which share the existing space on the rooftops. Since they are not directly connected to the existing building façade, there is no breaking rule at rooftop extensions. The re-appropriation grammar starts with the place/fix rule that defines the boundaries of the new extension. The other doing rules are applied similarly to the ground floor extensions.

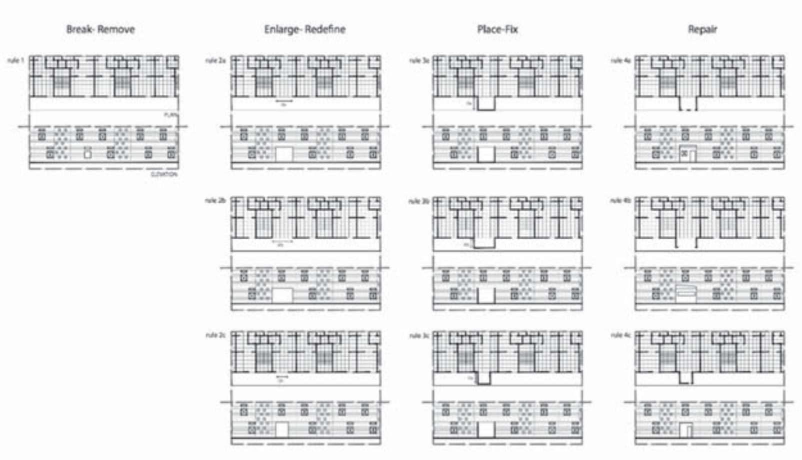

Figure 24.5

The doing rules: breaking for removing the existing frame, redefining for the new opening adjustment, fix for creating new walls and finishing for adding door, windows, and roof enclosure.

2nd Level of Appropriation

Façade openings such as windows and doors are defined as things and represented as 2D drawings. The inner components of the openings such as the wall, window frame and glass are defined as stuff. The doing rules are grouped under four main actions that generate user interventions. Figure 24.6 showcases the doing rules: breaking, redefining, fixing and repairing that generate the façade re-appropriation. The break rule represents the process of separating the existing building components from each other, which is basically removing the existing window frame from the wall. It is essential to apply this rule before any other rule. After this action is completed, it is possible to move to the next rules. The second rule is redefining the existing opening, this action is highly dependent on the competences of the resident. The tools and cost required at this level lead to a wide range of solutions. In some cases, the redefinition of the opening is directly related to window frame size available in the local construction market. In other cases, the walls are demolished in order to achieve larger opening or vice versa. Some French balcony openings are closed and transformed into standard windows. So, this rule demonstrates the redefinition of the façade opening boundaries. The third rule is fixing, a selected window frame is fixed to the redefined opening. The fourth and last rule is repairing, which is applied in case the selected window frame does not fill the redefined opening. The gap left after fixing the window frame is mostly filled with masonry. On other cases, it is enclosed either with transient materials for temporary solutions.

The labels 1, 2, 3, 4 in the doing rules control the sequence in which the rules are applied. However, each rule may be applied in different consequences in order to achieve the same action. Therefore, sub names such as a, b, c, etc. are introduced. There are many different ways to redefine, fix and repair user modifications and these are related to the competences and self-expression of the user. There may be as many sub-rules as users in each rule.

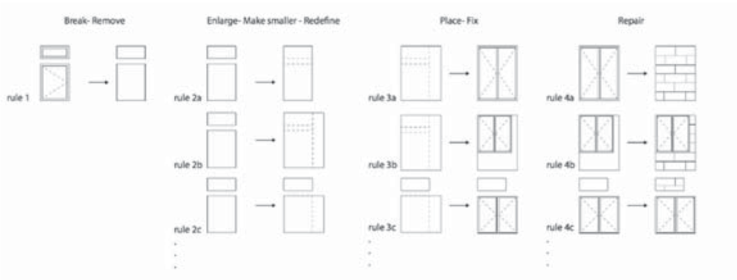

Figure 24.6

The doing rules: breaking for removing the existing frame, redefining for the size reappropriation, fix for relocating the window frame and repairing for the closure of the openings left.

3rd Level of Appropriation

Façade add-ons are defined as things and represented on 2D drawings as the previous appropriations. The inner components of these add-ons such as curtains and fences are defined as stuff. The doing rules are grouped under one action (Place/Fix) that generate them.

Conclusions

The approach adapted in this study involves using shape grammars with focus on spatial effects and making in order to depict the user's accommodation of the architecture of *Climat de France*. The aim is to illustrate and analyse the actions, and eventually motivations, behind user adaptations using spatial grammars. This study presents a preliminary grammar of the adaptations of a user oriented vernacular modification of the modernist architectural design.

In *Climat de France* the process of residents' making and doing consists of thoughts, self-expression and competence. Thoughts or ideas that trigger the impulse of making change in their living environment are a result of the dialogue between the person and home. As Habraken[7] points out, the control levels are the foundation on which we problematise the chances of regaining control over the housing process. The exclusion of the resident from the housing process leads to an alienation that may result in different consequences in different cultural contexts. DIY projects are popular approaches in more developed countries and are defined as *a desire of self-expression and an effort to resist alienating effects of the mass consumption.*[12] In the case of *Climat de France* residents modify their domestic space with bold intervention visible on the facades, rooftops and ground floors.

Three re-appropriation levels are analysed under four rules: breaking, redefining, fixing and repairing. The doing rules in this grammar are highly related to the competence of their makers. Residents' needs are identified as lack of space, practicality, light and air control, privacy and security and associated with the three re-appropriation levels. Shapes are embodiments of things and ideas of a precise socio-cultural context. The reflection of cultural aspects, user needs, challenges and interventions on the appearance of housing blocks such as *Climat de France* present rich data to explore and analyse through shape grammars. Shape grammars are indifferent to the terms of knowledge that create the shapes and labels are utilised to complement the visuals to include these terms. Although the same rules are applied in the same sequence the results can be completely different in practice based on "who", "how" and "where's of the application. Shape grammars, as enterprise, value doing and integrate it to the design process. The competence and user expression determine the appearance of the accommodation in *Climat de France*; hence their grammar is taken up as a spatial one with focus on making. Designing is redefined as a kind of making, demanding perceptual, bodily engagement with materials in the world. This definition of design is important in term of user appropriation, the process of making their intentions with the available sources and skills is a user-oriented design process. More studies are required to substantiate the aspects of making in the interventions before the grammar can extend to a making grammar.

References

1. Stiny, George & GIPS, James. *An evaluation of Palladian plans*. Environment and Planning B: Planning and Design, 5(2), 1978. pp. 199-206.
2. Knight, Terry & Stiny, George. *Making Grammars: from Computing with Shapes to Computing with Things*. Design Studies 41, 2015. pp. 1-22.
3. Duarte, José Pinto. *A discursive grammar for customizing mass housing: The case of Siza's houses at Malagueira.* Automation in Construction, 14, 2005. pp. 265-275.
4. Duarte, José Pinto, Roch, João M. & Soares, Gonçalo Ducla. *Unveiling the structure of the Marrakech Medina: A shape grammar and an interpreter for generating urban form*. AI EDAM 21, 2007. pp. 317-349.
5. Barros, Pedro, Beirão, José N & Duarte, José Pinto. *The Language of Mozambican Slums: Urban Integration Tool for Maputo's Informal Settlements*. eCAADe 31, 2013. pp. 715-725.
6. Benrós, Deborah, Duarte, José & Sean, Hanna. *A New Palladian Shape Grammar*. International Journal of Architectural Computing 10, 2012. pp. 521-540.
7. Habraken, John N. *The Structure of the Ordinary: Form and Control in the Built Environment*. Cambridge & London: The MIT Press, 2000.
8. Hooks, Bell. *Yearning: Race, Gender, and Cultural Politics*. London: Turnaround, 1991.
9. Miller, Daniel. Accommodating. In Painter C. (ed.), *Contemporary Art of the Home*. Oxford and New York: Berg, 2002. pp. 115-130.
10. Habraken, John N. *Supports: An Alternative to Mass Housing*. London: Architectural Press, 1972.
11. Ingold, Tim. *Making: Anthropology, Archaeology, Art and Architecture*. Oxon: Routledge, 2013.
12. Shove, Elizabeth, Matthew Watson. Consumption and Competence: DIY Projects. In P*roduct, Competence, Project and Practice: DIY and the dynamics of craft consumption*. Oxford: Berg, 2007. pp. 41-67.

II.3

Design Automation in Architectural Education

CHAPTER TWENTY-FIVE

FORM FINDING AND GENERATIVE SYSTEMS: A THEORETICAL AND APPLIED RESEARCH PROJECT

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ERNESTO BUENO, JARRYER DE MARTINO,
VICTOR SARDENBERG, DANIEL LENZ

Introduction, Generative Systems

The use of generative systems in design, unlike traditional methodology, implies an indirect relation with the final product. Production, rather than being done directly, with the "designer's own hands," is mediated by a "generative system", as Fisher and Herr point out[1]. A generative system is based on an abstract set of rules, capable of producing a set of variations that to have meaning must be able to translate a set of qualities in the domain they are applied. A generative system is a solution-seeking process that, when interacting with context, like other open systems, approaches natural evolutionary processes. Generative is an adjective that derives from the Latin word *generare*, it designates one who generates or has the property to generate; is relative to generation; in linguistics, is associated to the theory of grammar that establishes a model, structurally describing the generation of discourse from a set of rules.

Generative systems, by generating solutions beyond the imagined, allow expanding creativity. According to John Gero, the most common concept of creativity does not consider the ability to develop possibilities during the generation of results, only considering the ability to improve the quality of an end product.[2] To create multiple solutions is necessary to use a method that intensively explores the possibilities of solving a problem, to generate unexpected and less familiar results for its creator. In this sense, the concept of emergency, which is less valued in traditional project, should be more valued in generative processes. Irving Taylor,[3] classifies creativity into five levels: expressive, productive, inventive, innovative, and emerging. In the context of generative systems, it is important to emphasise beyond the "emergent creativity" the "productive creativity", that is, the creativity that is contextualised in the domain of a technique, which allows controlling the project in the environment where it is generated.

Since the 19th century, mathematics developed new models capable of supporting generative processes, even if they were not denominated as such. The formal discipline of mathematics has changed paradigm with the introduction of computational processes, based on probabilistic logic and evolutionary processes, like random search, swarm thinking, among others associated with the development of artificial intelligence. Generative design processes are now successfully used by professionals and researchers in areas such as graphic design, mathematical optimisation and materials engineering. Although the use of distributed computing allows creating numerous cycles of design possibilities, there is the difficulty of defining mathematically how to choose the best solutions. Generative systems have been used to search for solutions according to explicit objectives in certain types of problems, such as formal mathematical problems. Implicit search is used in other type of problems such as those that are not computable and those that are not clearly definable due to their complexity, as is often the case with many architectural problems.

The application of generative systems in Architecture is still residual, incipient, and in most cases, limited to visual issues or to the large urban scale. However, the development and application of generative processes is fundamental to solve the increasing complexity of design problems. Casey Reas is an example of the application of generative processes in visual arts[4]. The application of generative processes at the urban scale is associated with the seminal research of José Duarte,[5] advised by William Mitchell, one of the precursors of computational design at MIT. This research has been continued in Portugal by a new generation of researchers such as José Beirão, Nuno Montenegro, Sara Eloy, Alexandra Paio, among others. In Brazil, Gabriela Celani, who was also advised by Mitchell, developed a research on this area, followed by other researchers such as Benamy Turkienicz, José Cabral Filho, Daniel Cardoso, Fernando Lima, Robson Canuto, among others. Recent research at UFRJ has been developed by Maria Angela Dias and Margaret Chokyu. In architectural practice, Franklin Lee and Anne Save de Beaurecueil have been applying such techniques in professional practice. However, this urban research has found few applications at the mesoscale of project: that is, the scale of public squares or of temporary spaces like pavilions. The argument is that to transfer this methodology to the design processes it is necessary to study the context of application of the generative processes. Thus, we intend to map new generative techniques such as cellular automata, L-systems, genetic algorithms, and shape grammars, and test their application in design.

Given that generative systems act indirectly on results, they need to be interpreted, which requires developing a greater knowledge about the process itself. This implies not only using algorithms, but also being able to modify them. Thus, the generative systems approach is more of an open process, which finds its parallel in evolution, and in natural *morphogenesis*. Both synthetic and natural generative processes determine the evaluation of the results and the ability to modify and improve the algorithms. This evaluation and improvement can only be done through the information feedback of each generation. The improvement process allows the algorithm to no longer be considering a black box—for which we only know the results—to become a more transparent box in which we can interfere in its internal process of operation. In the process of developing solutions, one of the most important references is the difference between computerisation and computation processes, as referred to by Terzidis.[6] The combination of both processes constitutes *algorithmic design*, addressed in a previous article.[7]

On the Application of Generative Systems

Mathematical optimisation has a precise definition and is applied strictly. This optimisation is often used in a final design stage, after the form is defined, to improve its performance. For example, a roof structure can be developed using the traditional design process and then the end form can be optimised to improve structural performance. The search for design form beyond strict criteria also obeys implicit criteria belonging to ill-defined problems. These types of problems, because they are not easily translatable into logical parameters and criteria, are often avoided in the mathematical reasoning of engineering. However, these criteria are implicitly considered in architectural design processes. In order to find solutions, experience with the tools and their application are important for evaluating the solutions. Thus, it is necessary to study the development of algorithms, acting on the system generation and not directly on the results as in the traditional processes. In this sense, it is fundamental to study, through experimentation, how the mentioned techniques – cellular automata, L-systems, genetic algorithms and shape grammars – act in the development of the form. Namely, to study with each type of algorithms, what is possible to develop and to what kind of design problems can be applied.

Problem solving depends on multi-causal manner of the processes and techniques used, but also on the nature and type of the problems. Therefore, it was considered relevant to identify examples of success using the techniques mentioned, to develop its application to concrete design problems. Identifying the type of problems and how they were solved in a particular context is important to solve new problems. Thus, the interest in learning and experiencing these techniques is justified, to validate them empirically. It enables the researchers to become familiar with these types of processes, stimulating knowledge through action learning process.

Problem/Project Context

The preliminary research intended identifying simple solutions, using the referred generative techniques to solve design problems in a small/medium scale. The goal was to use generative design to solve a design problem, for an intermediate scale space between 3×3×3m (min.) and 10×10×10m (max.). The idea was to map the existing techniques to solve problems for this space, considering few variables. It is also intended to identify how to interact with generation through feedback. The idea was to develop a process of interaction of the algorithm with the environment, instead of using an inaccessible black box. This adaptation allowed us to approach generative design problems specific to architecture. The preliminary research to the seminar studied this problem, trying to identify similar situations, variables and contexts already tested. The application of these techniques was studied, among others, in public square projects, shelters, pavilions and constructive systems. The solutions depend on the tools and on the computational processes used. Thus, we sought to identify the search space and factors that interfere in this search, starting from generic to applied processes, in specific contexts.

The need to work with algorithms in a workshop of a diverse audience—graduate and postgraduate students, teachers, and professionals from different regions—led us to choose Grasshopper, a parametric 3D modeller by means of visual programming. It runs as a plug-in of the NURBS modeller Rhinoceros. The algorithmic nature of Grasshopper allows implementing generative algorithms without the drawbacks of learning a programming language; while its open policy enables the access to a great number of software add-ons for experimentation[8].

Cellular Automata

Cellular Automata (CA) are systems that operate locally, which means that the state of each cell in an n-dimensional grid is defined by its neighbours. CA was invented and developed in the 1940s by Stanislaw Ulam and John von Neumann and it has been applied in a broad number of fields, like Computer Graphics and Cryptography. However, besides its capacity of creating forms, it has not been so popular in the field of Architecture.

According to our traditional intuition, a system with simple input using simple rules would produce simple behaviour. However, CA is able to produce, from simplicity, emergent complexity, as it was demonstrated by Stephen Wolfram.[9] Given our historical moment's attraction to complexity, we can use CAs to generate it successfully.

The CA unpredictability: The workshop exercises introduced the students to the idea of *Form Making*, instead of *Form Finding*. The idea is to create an alternative for contemporary rational trends that advocate that architectural form can be undermined by simple quantitative criteria, like environmental performance, material use and cost reduction.[10] For each exercise with CA, the participants were invited to analyse the spatial and aesthetic qualities of each form and therefore interact with the system. One characteristic of CA is that it is impossible to predict its behaviour – there's no feasible way for foreseeing how a change in its rules would affect its product. Therefore, the way the designer interacts with the system differs from Albertian total control of the drawing. The participants were invited to approach the *form making algorithm* in a playful and horizontal way. *Estranging the Context* and *the Virtual Cocoon* are projects developed using CA based in a previous research about how computational morphogenesis can foster a new intuition to solve complex phenomena.[11]

CA Workshop Development

In the act of *form making*, there's an intention to not only create geometric patterns, but also geometry with an architectural meaning. In this way, during all stages of the process, architectural elements as slabs, windows, façades, or ramps were introduced or produced by the CA system in such a manner to give architectural meaning.

Two groups of students produced two projects. The first group *Estranging the Context* used the agile form making characteristic of CA to produce architectural elements that inhabit movies. Each movie, according to the mood of its genre (e.g., Sci-Fi, Comedy, and Horror), received an architectural installation that responded to it and at the same time altered it. The second group, *The Virtual Cocoon* used a three-dimensional CA to produce a four-dimensional object that can be explored in Virtual Reality. Usually, a 3D CA is presented as a series of cubes side by side. With VR, it is possible to experience it as a malleable virtual object. In addition, the inhabitant of the cocoon can interact with it according to its position in space (Figure 25.1).

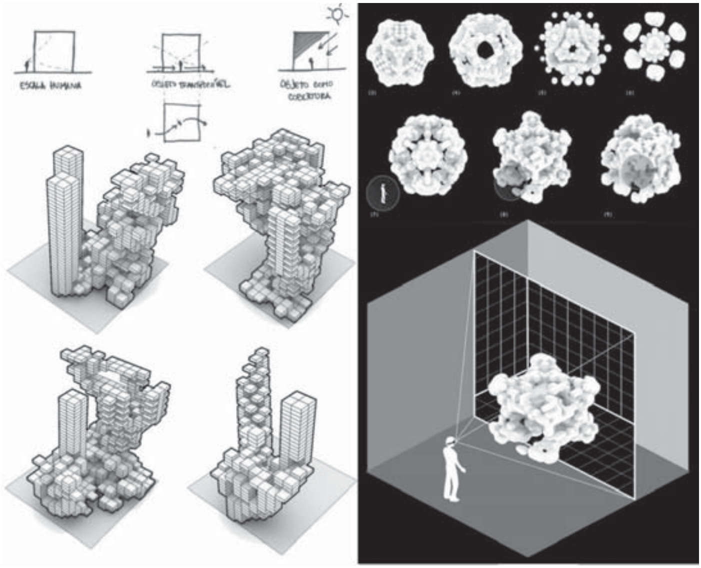

Figure 25.1

CA proposals, Estranging the Context, architectural elements that inhabit movies (group: Thatilane Loureiro, David Mendonça, Eugênio Moreira [left]) and The Virtual Cocoon a three-dimensional CA that produces a four-dimensional object to be explored in Virtual Reality (group: Nicolle Prado, Isadora Tebaldi, and Emilio Marostega [right]).

CA Workshop Conclusions

CA is a very fast method to create complex and intricate form if there is a playful interaction with the designer. However, it is always necessary to have a qualitative understanding from an architectural point of view. There's a difference in between creating *geometric patterns* and *architectural* *drawings*. The first can easily be created by generative computational systems and be optimised according to quantitative criteria. The latter requires a cultural understanding of the spatial and aesthetic geometrical arrangement, being a very specific type of drawing that can only be understood through qualitative criteria offered by the history of Architecture as a discipline.

L-Systems

This research studied the application of L-systems to solve design problems, by looking in the literature on the theme, but especially, by working on the technical implementation.

L-systems are symbolic systems capable of generating growth structures, based on the ability of rewriting rules recursively. They were discovered by biologist Aristid Lindenmayer (1925–89) to describe the growth of simple species such as bacteria and algae. The technique is based on three concepts: (i) axiom, also referred to as seed, that is the initial string of symbols, which represents the initial state of the system; to this seed are applied (ii) production rules, through (iii) recursion, a repetitive computational method, in which each generation is executed from the previous one.

Originally, L-systems, are formal and deterministic systems that does not consider the interaction of rules with the context. An L-system is deterministic, when there is one, and only one, substitution rule for each letter of the alphabet.[12] In order to extend the application of this generative technique, we searched for methods using visual programming to develop context-sensitive L-systems. With the possibility of reacting to the context, L-systems evolve from a characteristic representation of a single artificial plant to the ability of generating differentiated species over time.

Among the generative design references that are relevant to L-systems, there are Fisher[1] and Agkathidis.[13] A more practical reference is the book by Prusinkiewicz and Lindenmayer.[14] There were few applications in architectural design, so we searched for papers, identifying the methods such as those by Paul Coates *et al*.[15]

While working with Grasshopper, we evaluated different software add-ons to generate L-systems, like Rabbit.[16] This add-on has an interpreter that translates the code into turtle graphics. It was found that the interpreter only accepts as input, letter symbols and is deterministic. An application was sought to apply functions with recursive loops, enabling non-deterministic

L-systems. We tested *Hoopsnake*, used by Maycon Sedrez.[17] However, this application was unintuitive and presented some limitations. We tested *Loop*[18] and finally, we tested *Anemone*[19]. The latter is more intuitive, data order is maintained during loops and has an expandable list of data paths, enabling to change parameter values that affect each generation of form. It was thus possible to change the generation according to external factors and to implement turtle movement.

LS Workshop Development

Two groups developed L-systems, one designated *Menger Revisited: Interactive Black-Box* and the other, *L-Aquele (A)braço* (What could be translated freely to the hugging trees). The possibilities explored by the two groups are complementary. The first revisits the Menger sponge, proposing laws of recursive interactive transformations, in this case a fractal that changes according to the presence of the user, in a virtual topological space (Figure 25.3). It goes beyond the classical Menger sponge by breaking the symmetry in unpredictable, yet relational ways, without losing self-similarity. The second revisits the development of a tree-like structure, but in which its branches are re-configured according to human presence, changing the angles and planes of rotation according to this presence as an attractor (Figure 25.2). The system is in equilibrium when the user is in the centre of the space, and then is embraced by the trees. The first solution is virtually interesting, but difficult to be applied in the physical world. The second, despite following some stereotypes of a tree, has the type of mechanism that could be applied in an articulated physical structure.

Figure 25.2.

Perspectives of the project Menger Revisited, showing recursive system variations triggered by the proximity of the user (group: Fernando Lima, Aurélio Wijnands, and Maria Eloisa).

Figure 25.3

Perspectives of the project L-Aquele (A)braço, showing the movement of the fractal trees as the user passes by (group: Núbia Gremion, Erick Bromerschenckel, and Daniel Wyllie).

LS Workshop Conclusions

Cecil Balmond designates "formal" as a platonic Ideal, reduced to a set of rules.[20] By contrast, he designates "informal" as having non-linear design features. He also states that *the nature of reality is linked to probability, and that order is only a small local space, in a static state of a much greater random order*. In this sense, the projects developed confirms the possibility of (de)formalising a technique or a (re)naturalisation. This way both projects can continue to advance in the virtual world, as in the real analogue world. It is hoped that in the future some formalistic clichés may be lost, so that we will approach artificial-life systems, in-vitro.

Genetic Algorithms

The Genetic Algorithms (GA) are defined by a set of finite rules and operations that simulate the combination of the characteristics of the individuals of the same species, in order to select those that best satisfy the demands of the environment in which they are inserted. The algorithms are structured considering the main mechanisms present in the evolution of the species: genetic inheritance, random variation (crossover and mutation) and natural selection. Its application is related to processes of optimisation solutions, being widely used by engineering to optimise topologically structures, parts, among others. In architecture, the GA has been used for space planning, optimisation and generation of forms. Although it is a method of optimisation, it is possible to use it as a generator mechanism capable of assisting the designer in the process of exploration and investigation of the space of solutions, being possible to obtain the emergence of unexpected and creative results. In this context, the algorithm must be configured to obtain favourable solutions independent of the lower or higher level of optimisation obtained in the whole process, guaranteeing the flexibility of choice among the solutions generated. The main authors adopted as reference for development of the workshop were Holland,[21] Bentley,[22] and Mitchell.[23]

Grasshopper has its own generic solver, *Galapagos*, with offers GA functionality. However, it is limited in terms of possible design problems it can tackle[24]. The Grasshopper add-on *Biomorpher*[25] was used because it allows the designer to interact with the algorithm during its execution. The designer selects the “parent individuals” from objective criteria (numerical values related to optimisation) and subjective (evaluation of the composition aesthetics), directing the evolutionary process, once the “parents individuals” will be crossed to generate the “individual offspring”.

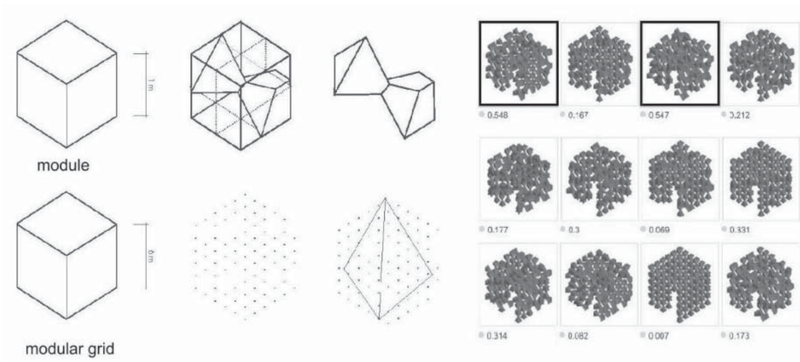

Figure 25.4

Group EA strategy and solutions (group: Luciana Gronda, Igor Machado, Monique Cunha, Wellida Coelho).

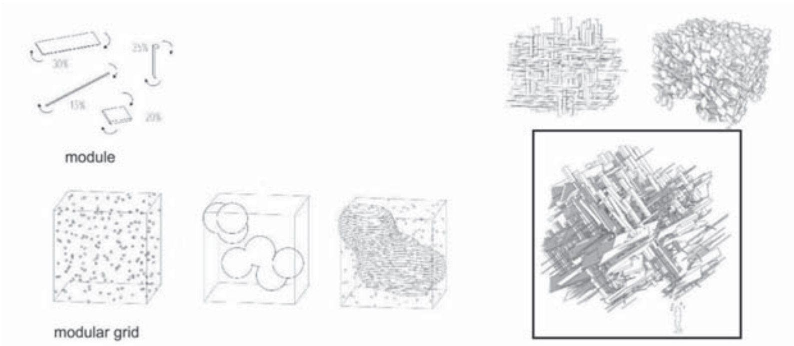

Figure 25.5

Group DD strategy and solutions (group: Anael Alves, Loan Tammela, Felipe Lannes).

GA Workshop Development

Two groups developed GA, one designated *Evolutionary Aggregation* (EA) and *Dwell Debris* (DD). They adopted as criteria the shading, the contact generated by the grouping of components and the formal composition. As a strategy for structuring the GA, the EA group opted for a regular three-dimensional modular grid for the distribution of modules, ensuring regularity and orthogonality to the project (Figure 25.4). The DD group opted for a cloud of randomly distributed points in space, giving irregular arrangements for the overall form (Figure 25.5). In both strategies, the void inside the structure was obtained by subtracting points that intersect a given solid located at the centre of the structure. The modules used by each group were quite distinct from each other. In EA, a single geometry capable of rotating on its own axis has been defined, generating different options of modules to be positioned in the grid of points. DD defined four geometries that also rotated in their own axis, generating a diversity of modules to be grouped and distributed in the cloud of points. The EA group programmed the GA to find solutions that had the largest contact surface between the modules and the largest projected shadow area. On the other hand, the objectives of the DD group sought to find the greatest number of intersections among the modules, greater volume in the lower dimensions and less shading.

GA Workshop Conclusions

The difficulties encountered by the groups during the workshop were not related to the use of the GA, but to the manipulation of the Grasshopper components and the structuring of the modelling algorithm. The first algorithm generated unwanted results. In this way, the groups needed to re-formulate both the strategy and the algorithm. This review contributed to improve the understanding of the design problem and also the recognition of the need to create mechanisms to control the generative system. In summary, the genetic generative system not only automated the process of generating forms but contributed to obtain more knowledge about the problem proposed by each group.

Shape Grammars

As there was no established software to run shape grammars in our context, we decided to develop a definition for Rhino/Grasshopper to emulate them. To do so, we got back to some Stiny's initial texts,[26, 27, 28] looking for elements to structure the definition. We identified a recurrent description that we organised into the triple ordinate [Equation (1)]:

$$G = (v, r, d) \tag{1}$$

Where G is the grammar, v the vocabulary, r the set of rules, and d a set with the derivation, i.e., the sequel of rules to be applied. In Stiny's classics, G, v, and r are always mentioned. However, d appears only in a latent form, never explicit, be as markers, or as different set of rules for each stage of development, or as rules applicable to specific shapes that only appear after a certain rule. Thus, we understood it better to assign an independent set to the derivation sequel for a more coherent general structure, with the benefit of also allow a more straightforward implementation.

Workshop Development

Our algorithm is understood as a protocol of concatenation between the three sets, while each set is allowed independence in its inner definition, as long as the protocol of coordination is observed. It is a loop with v as input, applying the rule from r indicated in d, accumulating the result in v. While v and d are simple lists, r is more complex. It takes two shapes, indicated as initial and final, memorises their relations of scaling and other Euclidean transformations, and then apply them to the input shape. This relation rule can be established either through Grasshopper coding or by drawing in the

Rhino canvas, with initial and resulting shapes as Brep inputs to this algorithm. There are some holdbacks to point out. The definition presented did not have any ability to recognise the shape it was dealing with, so it could operate a triangle related rule to a square, for instance. However, as work in progress this is a next step, along with the recognition of emerging forms. This overview structure turned out simple enough to encourage the teams to develop their own definition. After the initial presentation and exercises, one of the teams developed a Shape Grammar relating music to façade (Figure 25.6), while the other focused on designing a shelter (Figure 25.7). At the end, they either turned back to using our definition changing the rules, or to very similar dedicated shape/rule definitions. In either case, many designs were explored before deciding for the final one. As speculations over this work frame, we identified a few potentials, technically and conceptually.

Figure 25.6

Shape Grammars, re-scribing compositions (group: Daniel de Sá, Rodrigo Scheeren, Leonardo Prazeres).

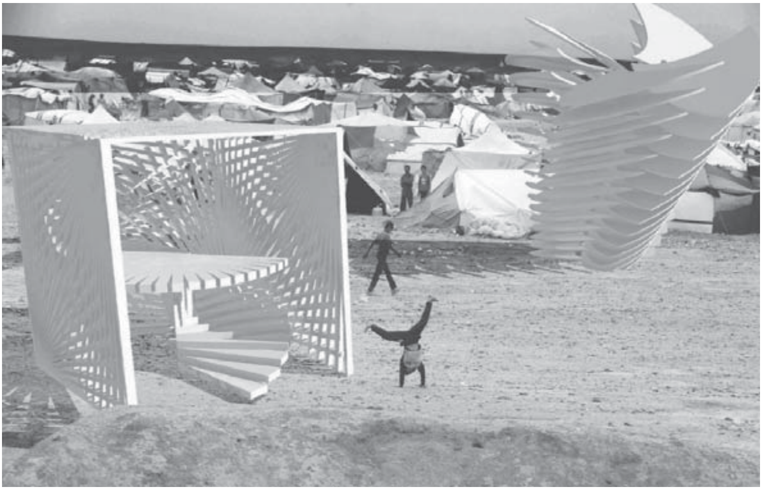

Figure 25.7

Shape Grammar, sheltering grammars (group: Lais Kaori, Rebecca Borges, Davi Ramalho).

SG Workshop Conclusions

Recognition of emergence could be easier done inside the operation of the rule, for which the result is known. The work frame definition with a set of shapes containing the initial and resulting shapes makes this easier.

The derivation ordinate plays a fundamental part in Shape Grammars. Usually they are taught as shapes and rules, and derivation remaining rather obtuse or unclear, as if it could be just chance. All the randomness has to be incorporated at the derivation. Therefore, full randomness probably leads to meaningless design. Some amount of randomness can be used and still generate some meaningful design. In this case, the derivation set must be treated as a decision tree, with different paths encoded, and the randomness used to change between them.

Conclusions

Roundtable Discussion

The final roundtable discussion was intended to reflect on the process conducted by tutors, seeking feedback from all participants. It allows us to reflect on the discoveries that preceded and happened during the event, valuing the association between theory and experimentation. The seminar began with tutorials, and then techniques were empirically tested during the workshop, evidencing the application of knowledge in design. The acquired practical knowledge was validated in design, expanding the initial theoretical knowledge.

The roundtable was triggered by questioning: how do the discovered tools interfere in the "form" found? This question was posed to each tutor, to reflect on the technique he used, identifying the advantages and limitations of each one.

Ernesto Bueno (EB): The presentations we have just seen from the projects are interesting and quite different. Groups explored generative processes differently. The eight projects have in common the fact that they are interactive, all based on simple rules, that in a first interaction are not complex, but that explore the potential of the computer, to take us to levels in which our capacity of natural and geometric comprehension would not take us. What is interesting, and has already been discussed since previous LAMO events, is how to use the computer as a design tool, which goes beyond the simple CAD drawing board. Parametric drawing can be very advanced for certain tasks, but it is still an automation of a series of processes, which ultimately depend too much on end-user software skills. Perhaps generative design does not have these limitations.

Gonçalo Castro Henriques (GH): What are the limits and advantages of L-systems?

EB: The main limitation was how to use the turtle graphics. We can see this in both L-system projects. The one of the trees that embraces us, made a more literal reading, although progressively got out of the rules of turtle graphics and created trees that open and close with an attractor, with rules that can be considered L-systems rules, but they do not exist in the classic turtle movement. The Menger sponge-based project is a recursive system which in essence is an L-system, but it was conceived from the beginning using different techniques. That made possible to deepen the exploration on what can be done with a fractal. This is fantastic. The limitations of the software are the ones we have always have. That is why I am a fervent adept at learning to program, to develop our own tools and not be limited to what the industry offers to us.

GH: When we started to prepare exercises on L-systems, the definitions we found did not predict interaction with the environment. This was a limitation that might explain why this technique, although old, is currently less used. We saw the possibility of changing the application of the technique through stochastic algorithms. However, the examples that we found resorted in programming only, which was difficult to implement in such an event. So, we look for and tested several applications for recursive cycles in Grasshopper with the ability to interfere in the growth with external factors. Both groups were able to interfere with growth cycles and create interaction with the environment. The results, as Ernesto commented, may be somehow literal and be applied to the project with difficulty, but I believe we have opened a new path, introducing new possibilities for research on the subject.

Victor Sardenberg: I found very interesting that usually in a workshop we start from a concept or an intention to generate a product and then the students discover what tools they need for designing this product. This time, we first found out what these tools can generate as a product, we explored them, and we let the students speculate on what they can do. Regarding the cellular automata, I have the impression that is almost a cellular autonomous, which is very difficult to make and to interact with. It works more like a form generation from which one tries to find an architectural sense. Thus, according to the process used, most projects ended up being close to a representation of that process. Perhaps the genetic algorithm, by not forcing such a specific form, brought the most freedom to produce results, which were not so expected. So, I would say that the advantage of the automata is the ability to generate many shapes, very fast; and the biggest difficulty is the lack of a clear architectural sense and the difficulty of interacting with it.

Jarryer De Martino: Regarding genetic algorithms, the result was good to show the possibility of using these algorithms which, although they are optimisation tools, they can also be used as generative tools. It was reinforced what we presented about generative design and this possibility, of being used as a shape-generation engine. Reinforcing what I had already foreseen in my PhD thesis, about this possibility of not only generating forms, but generating knowledge during the creative process, generating information, being able to review the process and its feedback. Genetic algorithms itself, reflecting on what Victor mentioned, works very much as a mechanism. I think that, because it does not have this link with the mapping of form, or modulation, it targets forces that are acting on that mechanism. Maybe it gives that greater freedom, because one defines genes and rules. It is a mechanism of automation of selection within that process. So, this workshop gave a good idea of the possibility of generating forms using genetic algorithms.

GH: Daniel, how was the experience of Shape Grammar? Not being your field, you decided to explore it in what it seemed like a rich experience.

Daniel Lenz: Shape grammars have been a little strange to me, because they dictate a set of rules, but this can be done blindly. We needed to have an object that was already coherent, so that this generated grammar could produce new coherent results. Other than that, this is speculation and just like in the cellular automata, you are going to have to cross your fingers and wish for it to work to get somewhere. However, some aspects were cleared, including the supervision that is needed for establishing the sequence of rules. I think that the interaction with the grammar is much out there. I found it excellent that in both groups, after establishing the working mechanism, each of them worked to develop their mechanism, or to customise it. It was a very interesting experience, mainly because we started with a certain disadvantage. In other techniques there was already a machine working in Grasshopper, but in grammar there was not. So, there is this great merit of the teams. I think that it was very clear that what will make the architectural coherence possible is the supervision at the moment that the rules are defined. Therefore, it is important when we decide that we are going to stop here and start on other side. An interesting research to be done is whether this supervision process can be coded, or whether it can be automated in something that envelops this grammar. This is the question that remains from this workshop about grammar.

Final Considerations

The event was an investigation that began many months ago with the aim of form finding using generative tools. In the opening presentation was mentioned Kostas Terzidis,[6] which distinguishes processes and design tools using the computer. In research in general the computer is being used as a process of computation. But it was important to show, and discover, the other side of the tool, of computerisation in the artistic sense, which is therefore considered more archaic, and contrary to what many think, the tooling or computerisation can coexist with the computation process, and this junction brings a new meaning to the form. The tool is somehow more tied to the context and limitations and potentialities of the project, albeit implicitly. But this process is not blind, benefiting from previous experiences, of trial and error, that even though they cannot be coded, they work as heuristics, which can help to define the computational mechanisms that we need to use in design. So, this use means rescuing the design intuition prior to the use of computation.

In this event we got lost well, experimenting with these form-finding tools, that may be useful in the future. The tools influence the processes, they are not neutral: they influence the final result and the solutions found. We thank and congratulate everyone for the excellent result. We thank all the organisation, the tutors, the lecturers, the participants, the volunteers and everyone present. It is undoubtedly a joint effort and we are all to be congratulated.

Figure 25.8

Em busca da forma, sistemas generativos: group photo by Nico Batista.

Research Credits

Coordination of the event: Gonçalo Castro Henriques, Andrés Passaro, Maria Elisa Vianna. Preliminary applied research: Cellular automata: Victor Sardenberg, L-systems: Gonçalo C. Henriques, Ernesto Bueno, Genetic algorithms: Jarryer De Martino, Shape Grammars: Daniel Lenz; Interaction: Lucas de Sordi, Laura Lago. This text is the result of a joint research that was initiated at LAMO. In the prospective research on generative systems applications, participated: Andrés Passaro, Caio Cavalcanti, Cintia Mechler, Elisa Vianna, Erick Bromerschenckel, Gabriel Gaspar, Giordana Pacini, Isadora Tebaldi, Julia Nodari, Lais Kaori, Loan Tammela, Nicolle Prado,

Rebecca Borges, Roberto Costa Matta, Pedro Engel, Thiers Freire, and Vinícius Lucena, among others. This first research fed the initial text, and vice versa. The text began to be written by Henriques, and later commented and reviewed with the contribution of Sardenberg, Martino, Lenz and Bueno. This joint paper helped to define the theme, the methodology and to search for the tools. Scientific Committee: Andrés Passaro, Daniel Lenz, Denise P. Machado, Eliane Bessa, Gonçalo Castro Henriques, Guto Nóbrega, Maria Angela Dias, Rodrigo Cury: Federal University of Rio de Janeiro, Brazil; Ernesto Bueno: Positivo University, Curitiba, Brazil; Gabriela Celani: Campinas State University, Brazil; Jarryer De Martino: Federal University of Espírito Santo, Brazil; José Duarte: University of Pennsylvania, United States; José Pedro Sousa: University of Porto, Portugal; Mauro Chiarella: National University of the Coast, Argentina; Rebeca Duque Estrada: University Stuttgart, Germany; and Victor Sardenberg: Gottfried Wilhelm Leibniz Universität Hannover, Germany. Photography: Caio Carvalho, Luciana Willi, and Nicolas Batista. Video: Diogo de La Vega; collaboration Laura Basile.

References

1. Fisher, Thomas. Herr, Christiane. "Teaching generative design", in: Proceedings. Fourth International Conference on Generative Art, 2001.Available: papers.cumincad.org/data/works/att/c78f.content.pdf
2. Gero, John, "Creativity, emergence and evolution in design", *Knowledge-Based Systems*, vol. 9, no. 7, pp. 435-448, 1996. doi:10.1016/S0950-7051(96)01054-4
3. Taylor, Irving "The nature of the creative process", in: *Creativity: An examination of the creative process*, P. Smith, Ed., New York: Books for Libraries Press, 1972, pp. 51-101.
4. Reas, Casey., "Process/Drawing", *Architectural Design*, vol. 76, no. 4, pp. 26-33, 2006. doi:10.1002/ad.290 See also: How to Draw with Code, 2012: https://youtu.be/_8DMEHxOLQE
5. Duarte, José Pinto, "A Discursive Grammar for Customizing Mass Housing: the case of Siza's houses at Malagueira", *Automation in Construction*, vol. 14, no. 2, pp. 265-275, Mar. 2005. doi:10.1016/j.autcon.2004.07.013
6. Terzidis, Kostas. *Algorithmic Architecture*. Oxford: Architectural Press, 2006.
7. Henriques, Gonçalo Castro, "Algorithmic Architecture: Techniques, processes and fundamentals", presented at: IV ENANPARQ,

Session 39. Digital design and fabrication in architecture: Teaching, research and challenge, PROPAR - UFRGS, Porto Alegre, Jul. 2016. Available:www.researchgate.net/publication/305827549
8. Bueno, Ernesto. “Grasshopper”, in: *101 Conceitos de Arquitetura e Urbanismo na Era Digital*, Braida, F. et al., Orgs., São Paulo: ProBooks, 2016, pp. 118-119.
9. Wolfram, Stephen, *A New Kind of Science*, Wolfram Media, 2002.
10. Carpo, Mario. “Digital Darwinism: Mass Collaboration, Form-Finding, and The Dissolution of Authorship”, *Log Magazine*, 2012.
11. Sardenberg, Victor. “Processos Emergentes em Territórios Informais”, B.Arch. Diploma monograph, Mackenzie Presbyterian University, São Paulo, 2013.
12. Martins, João Manuel dos Santos, “Sistemas de Lindenmayer: Modelação de árvores com recurso ao Maple”, M. S. thesis, University of Porto, Mar. 2008.
13. Agkathidis, Asterios, “Generative Design Methods - Implementing Computational Techniques in Undergraduate Architectural Education”, in: Proceedings. the 33rd eCAADe Conference, vol. 2, 2015. pp. 47-55. Available:
papers.cumincad.org/cgi-bin/works/paper/ecaade2015_18
14. Prusinkiewicz, P. Lindenmayer, A. *The Algorithmic Beauty of Plants*. New York: Springer-Verlag, 1990. Available:
http://algorithmicbotany.org/papers/abop/abop.pdf
15. Coates, P. Appels, T. Simon, C. Derix, C. “Current work at CECA”, In: Proceedings. Fourth International Conference on Generative Art, 2001.
16. Dimitrova, G. and Mandov, K. “Intro to L-systems,” *MORPHOCODE*, 17 June, 2014. [Online]. Available:
http://morphocode.com/intro-to-l-systems/
17. Sedrez, M. Meneghel, R. “Projeto paramétrico com fractais no detalhamento de uma fachada,” *PARC Pesquisa em Arquitetura e Construção*, vol. 4, no. 2, pp. 22-29, Dez., 2013.
doi:10.20396/parc.v4i2.8634548
18. Turiello, Antonio. “Loop”, *Food4Rhino*, 27 Nov., 2013. [Online]. Available:www.food4rhino.com/app/loop
19. Zwierzycki, Mateusz, “Anemone”, *Food4Rhino*, 14 Dec., 2015. [Online]. Available:www.food4rhino.com/app/anemone
20. Balmond, Cecil. JANNUZZI, M. SMITH, R. *Informal*. London: Prestel Verlag, 2002.
21. Holland, John, *Hidden order: how adaptation builds complexity*. New York: Basic Books, 1995.

22. Bentley, Peter, *Evolutionary Design by Computers*. San Francisco: Morgan Kaufmann Publishers Inc, 1999.
23. Mitchell, William, *An introduction to genetic algorithms*. Cambridge - MA: The MIT Press, 1999.
24. Rutten, David. “On the logic and limitations of generic solvers”, *Architectural Design*, vol. 83, no. 2. pp. 132-135, 2 Apr. 2013. doi:10.1002/ad.1568
25. Harding, John. *Bio*z on the generation of the Chinese lattice designs”, *Environment and Planning B*, vol. 4, no. 1, pp. 89-98, 1977. doi:10.1068/b040089
26. Stiny, G. Mitchell, W. “The Palladian Grammar”, *Environment and Planning B*, vol. 5, no. 1, pp. 5-18, 1978. doi:10.1068/b050005
27. Stiny, George. “Introduction to shape and shape grammars”, *Environment and Planning B*, vol. 7, no. 3, pp. 343-351, 1980. doi:10.1068/b070343

CHAPTER TWENTY-SIX

SUPERGRID: A GRAMMAR FOR A KIT-OF-PARTS PEDAGOGY

PEDRO ENGEL

Introduction

The *Supergrid* is the product of an on-going research project linked to a first-year design studio in the Federal University of Rio de Janeiro which employs kit-of-parts exercises as part of its pedagogical strategy. Notably, such didactic method shares some key principles with the realm of generative grammars, since both rely on limited universes of elements and the establishment of combination rules. The *Supergrid* is essentially a grammar based on a three-dimensional structural grid developed as a computational algorithm intended to produce physical models that serve as didactic aids for presenting fundamental issues regarding architectural form. The first generation of models, presented here, privilege structure and closing systems of buildings and aims at an understanding of the façade as a mediation device between inside and outside. The models are intended to operate as three-dimensional catalogue that explicit numerous possibilities of combining basic architectural elements. The automated design method allowed by the algorithm, combined with digital fabrication tools, are intended to enable the production of large quantities of such models, thus providing didactic material for five different teaching units.

Aside from such practical outcome, the development of the grammar also permits research development in the use of generative grammar since it can be understood as an empirical experiment in designing an automated design system based on a specific formal grammar. In this sense, the goals of this article are two-fold: firstly, it aims at describing the process of development of the *Supergrid* so far; secondly, and more importantly, it intends to outline specific topics for the further development of the algorithms, which will expectedly set out directions in terms of resources and computational technology to be brought in the research in its next phases.

The paper begins by presenting the premises of the kit-of-parts pedagogy and the definition of the formal elements that compose the grammar and their syntactic relations. In the second part, the paper explains the development of the computational algorithm describing the types of elements that compose the models and the rules that govern their selection and positioning in the grid system. Considerations regarding further development will concentrate on different method s for selecting elements and their arrangements. Finally, discussion regarding different approaches to selection methods will be held with the intention to bring up the issues are at stake when opting for either a more controlled choice system or a more automated one.

A Didactic of the Kit-of-parts

The pedagogical agenda that guides the course "Concepção da Forma Arquitetônica 2-CFA2" [Conception of Architectural Form 2] involves the use of a kit-of-parts didactics, which consists in employing design exercises that use a restricted repertoire of geometric elements and a set of combination rules that define their possible relationships. The combination of elements and rules can be understood as the basis of a specific architectural grammar which, as we will see, can be formally coded.

It is important, however, to know the context in which the *Supergrid* emerged. It by no coincidence that kits-of-parts are present in well-known and celebrated didactic approaches, such as in the abstract compositional method developed by Durand[1] at the French polytechnic school in early nineteenth century or in John Hejduk's nine-squares exercises[2]. The adequacy of the kit-of-parts to the teaching of design introduction, it can be argued, is due to the existence of an intrinsic systemic order that guides the composition of the elements and, therefore, facilitates the formal conception for the beginner students[3]. Putting in motion the action-and-reflection exercise of the design process is important because it allows students to gain instrumental resources, to exercise design reasoning with relative autonomy and, more importantly, permits teachers and students to build a common basis of design issues and criteria. The kits also assist the novice student to make connections between the abstract representation of models and drawings, on one hand, and the building, on the other, since the geometric elements of the kit—planes and linear parts, for example—are directly associated with architectural entities—respectively, walls and slabs, pillars and beams—especially when easily recognisable scale references such as the human figure are provided.

The limitations in the universe of forms used in a certain kit imply, however, in directing the architectural visual vocabulary. In the design studio that gave origin to the *Supergrid* the parts of the kit are mostly restricted to the elements of the independent structural grid, closures (opaque, transparent, and perforated) and the sunlight protection components. Beams, pillars, slabs, walls, windows, glass panes, balconies, terraces, canopies, blinds, etc., comprise repertoire of elements that, although not impervious to re-signification, are common and ordinary. Notably, these are the components that the rationalist tendencies of modern architecture sometimes share with the buildings made by non-architects, typical of urban peripheries in developing countries[4]. Thus, the kits' formal library is based on exemplars of Brazilian modern architecture, but also on ordinary buildings of the periphery of Rio de Janeiro, a two-fold source chosen for pedagogical reasons: it aims at a common ground language compatible both to local construction know-how and to the cultural background of Brazilian erudite architecture tradition.

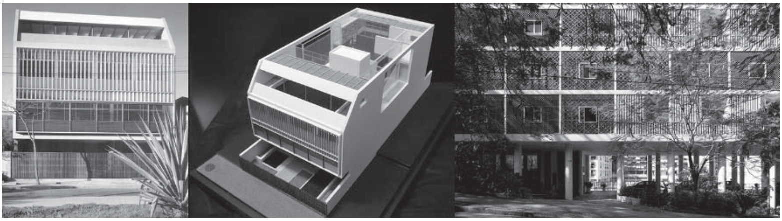

Figure 26.1

Examples of mid-century modern Brazilian architecture. Left: Antônio Ceppas House in Rio de Janeiro, by architect Jorge Machado Moreira, 1950. Right: Bristol Building in Guile Park, Rio de Janeiro, by architect Lucio Costa, 1950.

Figure 26.2

Examples of ordinary building by non-architects in the periphery of Rio Janeiro.

However, although the kit-of-parts may comprise a specific formal universe to be shared by students and teachers, the pedagogical intention goes beyond the teaching of such specific language. As has been mentioned, the kit's limitations favour focusing on specific architectural issues in the studio. In the case of the exercise called "Modulation", which gave origin to the *Supergrid*, the design of the urban façade conceived as an interface is intended address fundamental questions, such as the relationship between support structure and closures, the visual composition of the façade or the mediation between interior and exterior. Hence, the exercise aims at enabling students to develop the capacity of evaluating the combinations of elements and their relative positions in terms, for example, of building performance and social use of space.

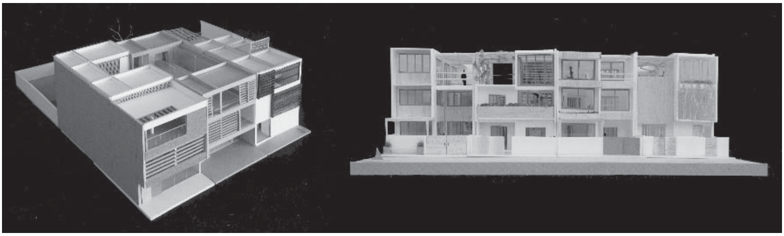

Figure 26.3

Student work in the studio. "Modulation" exercise. Prof. Pedro Engel and Ayara Mendo, 2017.

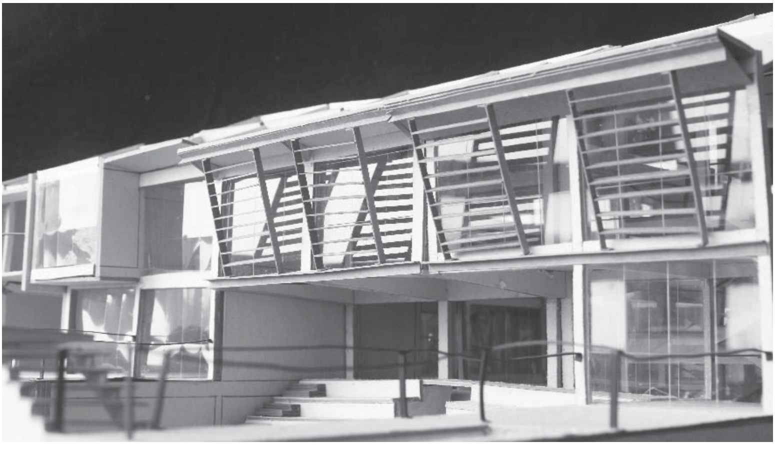

Figure 26.4

Student work in the studio. "Modulation" exercise. Prof. Ayara Mendo, 2017

Figure 26.5

Student work in the studio. “Modulation” exercise. Prof. Ayara Mendo, 2017

As may be expected, presenting exemplars of projects that have successfully employed the kit—or a variation of it—is a key aspect of the teaching process. Although a collection of images was created along the years, the presence of physical models of previous students in the studio proved very effective in explicating multiple aspects of a façades design. Thus, the discipline coordinators perceived the potential gains of constructing a collection of physical models, a kind of catalogue based the specific to the grammar of the discipline. Thus, the engagement in this research project, which aims to develop—through computational form generation and digital manufacturing methods—an algorithm capable of engendering an extensive quantity physical model. What follows is the description of the first stages of this effort.

To Encode a Grammar

In order to develop the algorithm, it was necessary to define the elements and rules that composed the grammar. A study of sever different façades of Brazilian modern buildings was made to encounter recurrences in formal characteristic. The grammar did not always follow strictly the examples, being usually adapted towards more simple solutions and to meet the typical formal solutions already used in the productions of student work, which included the presence of beams and slabs (a feature normally seen in mode ordinary building practices that use reinforced concrete in Brazil). This became what was called a loose analytical grammar.

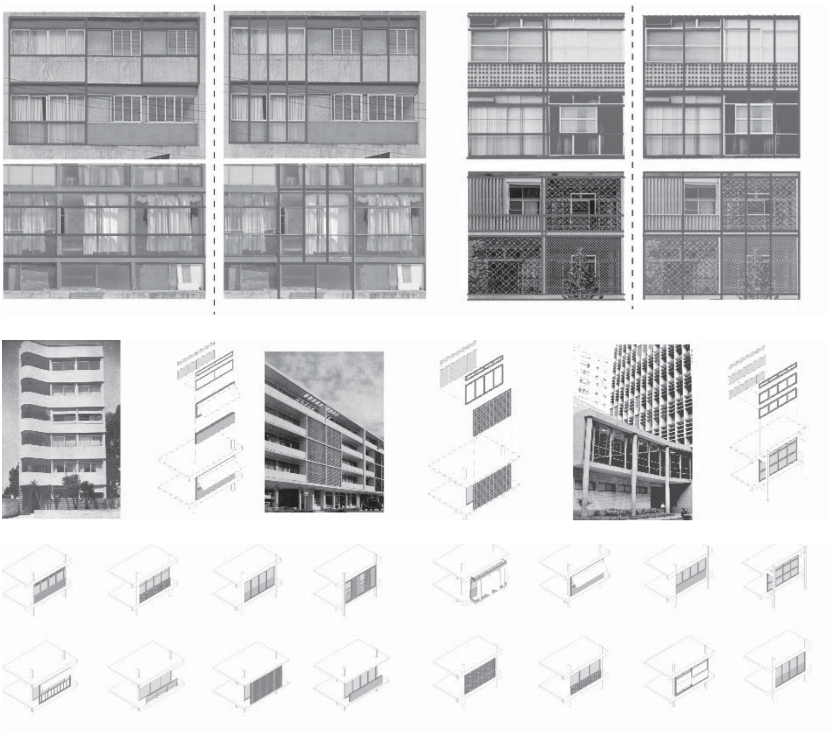

Figure 26.6

First stages of the analysis of façades of Brazilian modern architecture and its adaptation into a formal grammar if typical infill architecture.

The development of this algorithm poses a double challenge: on the one hand, to produce a parametric digital model, through Grasshopper, capable of generating variations in the composition between elements, controlled or predicted), and on the other, allow the production of physical models through digital manufacturing.

Physical Models

A Building Game

Aspects related to the production of the physical models were prioritised from the initial moment, since there were significant restrictions in the means production (limited to laser cutters and flat materials).

As is typical in physical models, the combination of parts follows a rationale that is specific to the model and differs from that used either in the design process or in the construction of the building. From an early stage it was established that the models must meet some characteristics: they should focus only on façade solutions, from the ground floor to the roof; should favour agile and precise assembly; should be in the 1:50 scale (the same as the student's projects); and should be produced mainly from laser-cut 3mm m.d.f. boards (although the closures could admit other materials). As a consequence, the separation of pieces in the physical model was intended be minimised to allow faster assembly and the dimensions of all parts became should be multiple of 15cm in order to meet the thickness of the board (3mm in 1:50=15cm).

The grid system was organised in such a way that the main façade was always parallel to the xz plane and runs several modules repeating along the x direction, with a height of at least three floors.

For the structure, three families of parts were defined: *ribs, x-axis beams* and *slabs.* The *ribs* are parallel to the yz plane, thus perpendicular to the façade, and contain all pillars and the y-axis beams. They are cut in large single pieces and so providing rigidity for the whole structure.

The *x-axis beams* run along the façades and inner axis. These beams are preferably continuous but may have to be segmented. They are made of double MDF sheets, the inner one always lowered to fit the *slabs* they support. The *slabs* form the floors and roof, being made of single m.d.f. pieces.

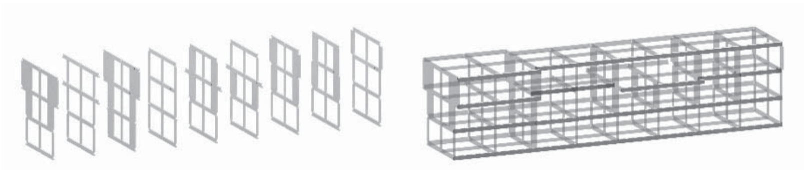

Figure 26.7

Parts that compose the structure of the physical models. On the left, just the ribs, on the right, ribs and x-axis beams.

The system was devised to allow for syntactic variations in terms of the sizes and relative positions of these elements. Façade beams can recede from the façade plane or can be extended, eventually forming a balcony. The pillars may be also extended or recede and can be stretched to form long rectangular sections perpendicular to the façade. The slabs may or may not overhang beyond the beams to form thin balconies and be absent or receded to form double height spaces. These variations have significant implications in terms of how the pieces of the structure are connected to each other. To absorb these variations a joint system was devised using a virtual grid of 15x15x15cm that applied both to the shape of the *ribs* and *x-axis beams.* The regular grid guiding joint system proved to be very practical, allowing several different types of joints to be designed and brought into the algorithm during its development.

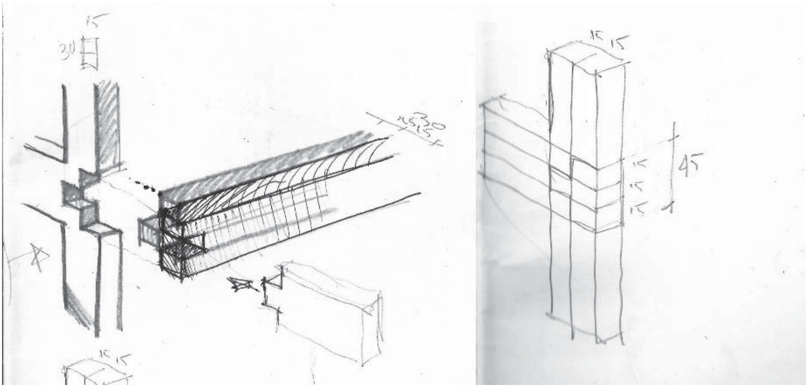

Figure 26.8

Initial design of the joint system: a 15x15x15cm grid allows several types of joints.

The closure elements followed a standard orientation proposed in the studio for student projects, all closing planes are conceived as independent from the structure. Even if they are aligned and covered by any kind of revetment, there should be a line marking the separation between structure and wall. Hence, all closing elements were conceived in the model as independent rectangular planes. The 3mm m.d.f. boards formed walls, both opaque and perforates, and 1mm Plexiglas was used for glass, while thick brown cardboards were used to make the glass panes division and outer solar protection.

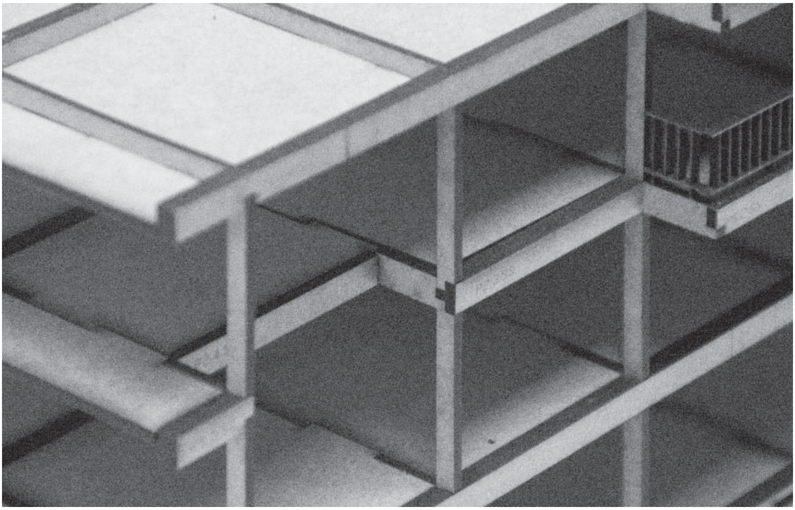

Figure 26.9

Fitting system designed for the physical models.

It needs to be recognised that the system is subject to formal limitations, since variations occur only in the y direction, while the positions in the x direction keep a regular pace along the whole model. Future development will attempt to provide variations in structural in the x direction as well. One intention is to allow different spans in the façade by supressing pillars or repeating pillars, for instance, with due consequences in terms of beam heights. Still, to have established a consistent definition for a formal system regarding the physical models before entering the coding phase was key to provide a guideline for the computational modelling, as will be seen.

Computational Model

The digital model of the *Supergrid* was developed in Grasshopper. As has been mentioned, it was intended to allow for a variation in compositions based on a specific formal grammar while simultaneously producing the line drawings suitable for laser cutting the model pieces. Also, it was expected to generate presentable digital images allowing the *Supergrid* catalogue to exist in medias other that the physical models. Hence, the digital algorithm should produce simultaneously a double output: 3D images and 2D drawings for fabrication.

The global organisation of the model starts from a three-dimensional grid of points corresponding to the nodes of the structural grid. Although intervals between nodes were regular, parameters have been assigned to define the quantity of structural modules as well as sizes of spans and floors heights. If this was a simple task, the challenge was to program the exact position of the actual structural elements in each façade segment, which required dealing with several variables at the same time. For example, concerning the *x-axis beam* and *slab,* three variables were at stake: the position of the beam in relation to the façade plane; the presence or not of the slab; and the position of the slab (coincidental with the beam or not). Depending on the combination of these variables, the actual shape of each joint was affected, resulting in a number of combinations perhaps too large for handling effectively. Two solutions were adopted in order to facilitate the handling of the algorithm. Firstly, the positions for each element were limited to just a fewer choice (the beam, for instance, was limited to 5 different positions: aligned with the pillar; advancing 15cm, advancing 120cm; receding 15cm; and receding 120cm). Secondly, instead of establishing free and independent parameters for each variable individually, they were organised in sets. For example: beam receded 1 module, slab present, coinciding with beam; beam in normal position, slab absent; beam advanced one module, slab present, coinciding with beam; and so on). This meant that instead of design specific positions for each part of the model, one can only choose among different types of solutions that were pre-set in the computer model.

The typological solution was employed throughout the *Supergrid's* development. Seven types of façade segments were established for the intermediate floors, each holding definitions in terms of the *x-axis beam's* position, the presence or not of the *slab*, and the position of the *slab* in relation to the *x-axis beam*. Also, four types of façade were used for the roof and, for now, only one type for the ground floor. The wall variations were conceived in types as well: each closing plane was divided in 3 vertical and 3 horizontal segments, which were grouped to form either opaque or permeable areas (glass, perforated wall or simply unfilled). Twenty-seven types of closing planes were defined, embracing several different positions for the openings, ranging from the totally permeable to the totally opaque closure. Also, four types of external panels were designed, as well as 3 types of *brise-soleil,* 2 of balcony closings and 6 combinations of horizontal planes for solar protection. The idea behind setting up the grammar in terms of types of elements facilitates significantly the control of the formal variations within the computer model. For instance, when opting for the presence of a balcony in a certain portion of the façade one can simply chose façade type number 5, instead of determining the extension of the slab, the position of the beam, the respective heights of its two components, etc. Putting in another way, the option for a certain type of façade triggers a series of decisions that are previously concatenated in the algorithm. This is a key feature of the computing model, especially for determining the specific joint type used in each node. Note that the joint design has implications, in each node, both in the cut of the *ribs* and *x-axis beams* and that it varies depending on the position of the two neighbouring beams that reach a specific node. Having eleven different types of façades results in no less than 29 different types of joints for the *ribs* and 43 types for the *x-axis beams.* Devising this joint typology required exploring all combinations possible before writing the computer definition. Within the algorithm the selection of joint types required the use of Python coding in which each combination of any two beam positions in a certain node led to the choice of specific shapes for *beams* and *ribs*.

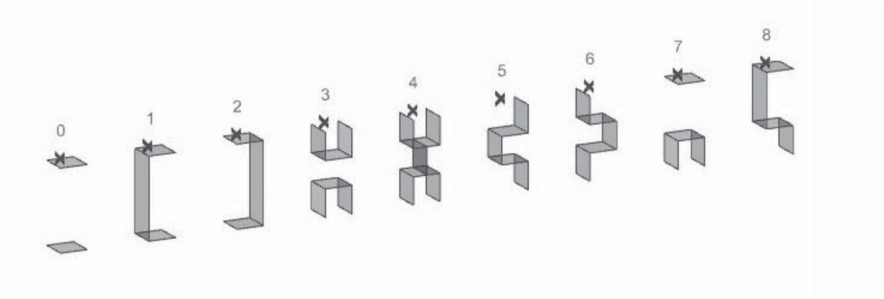

Figure 26.10

Examples of joints the x-beams. These shapes are inserted in the end part of each beam segment, allowing both its continuity into the next segment or its proper capping in case the next segment is inexistent.

The Python coding solution was employed of the model where there was only one right solution for each combination, hence the computer coding could offer the precise and unequivocal solution needed. However, the selection of elements that comprise a composition within a kit-of-parts is to great measure subject to choose (after all, this is the spirit of the exercise). In *Supergrid*'s algorithm the selection is, so far, mostly done "manually", through Grasshopper components like "value list" or "gene pool". The issue of selection is, however, an aspect that calls for better development in subsequent phases of the *Supergrid.*

One problematic aspect concerns the interface. A list of number is not very friendly interface for choosing elements of visual and formal nature. Hence, the necessity emerged for proper visual aids. A simple solution envisioned is to design a catalogue that relates the type numbering (wall type 12, for example) to a correspondent image. Even better would be the development of a digital interface that is visually based.

Another challenging aspect of the selection method regards the conditioning amongst different categories of types (structure, walls, protections systems, etc). There is nothing, so far, relating the selection of parts amongst each other besides their basic geometric features (extensions and positions). This means that the choice of a balcony, for instance, does not thoroughly relate to the choice of closures or to the choice of sun protection elements that will go together with it. Hence, there is nothing impeding to have a balcony with no doors leading to it or having brise-soleil installed in front of an opaque wall, for example.

Conditioning the choice of certain elements to the presence of others seems key to prevent “wrong” solutions from happening. Such coding may allow for a random selection of types that does not end up in absurd solutions, or better, it may permit to correlate the choice of elements to external factors.

Thus, further development calls for coding solutions that condition choices of types transversally amongst categories, probably allowing for a greater degree of automation in the process designing the models. But if coding may allow for automation, one must question whether a possibility of “manually” selecting elements and playing with compositions within the grammar is a hindrance to be overcome or a desired feature.

The brief discussion that follows tries to shed a light on what is at stake in terms of selection method to be used in the *Supergrid*’s further development.

Discussion

The possibility of “manually” selecting the elements that compose a certain façade segment, it can be argued, is part of the fun inherent to the *Supergrid* if seen as a toy-like kit-of-parts. Playing composition may permit one to investigate compositional possibilities inherent to the architectural grammar encoded in the algorithm. Considering the objective of such operations is to build a catalogue e in the form os physical models, such flexibility may instigate the teachers to operate as curators, for they will be compelled to provide some sort of ordering to the display of façade solutions, more or less in the way a collector is prone to organise his collection when facing the task to exhibiting it. On the other hand, manually choosing the elements can be seen as limitation if considering the potential of the *Supergrid* as an automated system. As it has been mentioned, conditioning the selection of elements though coding may have rich potential in terms of considering contextual pressures for selecting façade composition. One path that will be explored is to calculate the angle of the sightlines coming in and out of the building towards the street, a kind of assessment that may condition the shape of the openings or the opacity of the closing planes depending on the level of privacy intended for a given space. In this case, visual permeability could become one solid criteria for arranging the composition of the discipline's catalogue.

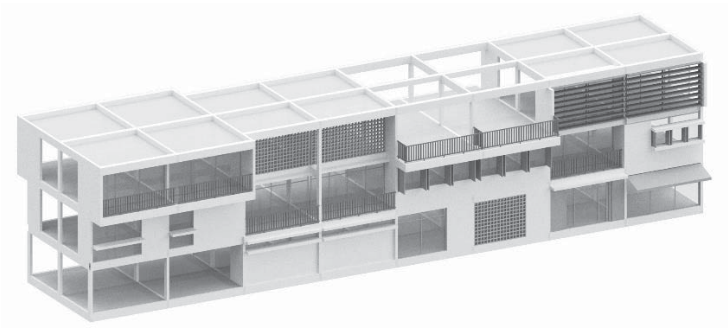

Figure 26.11

Example of a composition generated with the *Supergrid* algorithm. Rendered digital model.

Conclusion

So far, the development of the *Supergrid* is on the verge of accomplishing its purpose: allowing the production of a large quantity of models composed with a specific architectural grammar. However, some aspects of the algorithm design must be addressed in further development to better achieve its potential goals as an automated system, two of which have been highlighted here. Firstly, a visually based user interface must be conceived for a more efficient operation. Secondly, coding must be developed that relates compositional choices amongst different categories of elements for both avoiding unwanted solution and for relating compositional choices to external objective factors.

References

1. Szambien, Werner. *Durand and the Continuity of Tradition*. In: Middleton, Robin. *The Beaux-Arts and the nineteenth-century French architecture.* Cambridge: The MIT Press, 1982.
2. Caragonne, Alexander. *The Texas Rangers*: Notes from the Architecture Undergound. Cambridge: The MIT Press, 1994
3. Love, Timothy. *Kit-of-Parts Conceptualism*. In: Harvard Design Magazine, n.19, 2003.
4. For a deeper understanding of the pervasiveness of the architecture of the modern movement in cities that witnessed fast urbanization processes in mid-twentieth century see Aureli, Pier Vittorio, *The Domino Problem: Questioning the Architecture of Domestic Space.* In: Log, No. 30 (Winter 2014), pp 153-168.

CHAPTER TWENTY-SEVEN

A GENERATIVE SYSTEM USING SHAPE GRAMMAR: A CASE STUDY VISUAL PROGRAMMING

DANIEL LENZ

Introduction

Generative Systems are not an easy concept to point out the boundaries, though the general idea is rather simple. It should be an algorithm, that means, a series of specified procedures able to generate a set of solutions for a certain design proposal, ideally implemented on a computer program. The main objective of the workshop was to explore this concept and limits through testing on computational environment design exercises using techniques generally accepted in other fields of research as generative systems: Cellular Automata, L-systems, Genetic Algorithm and Shape Grammars.

The workshop was supported by a previous research of these techniques and literature done by the tutors, and organised in a 10 day intensive course. A series of classes and tutorials were held to then be applied in a design problem, that of a space between 3x3x3m up to 10x10x10m to be used for a pavilion or other public use space, depending upon what the technique was felt more prone to. We used Rhino as the 3D modelling tool, emphasising on its visual programming environment Grasshopper for the algorithm's implementations. In this work, we focus on the results related to Shape Grammar.

Preparation

Design Procedures

The computational implementation of Generative Systems poses two immediate categories of question: those related to design procedures and those about how to implement, or translate them, into computer coding. In order to be coded into computational language, a procedure must first be described as an algorithm, which means a sequence of precise tasks to be executed. Design breaking as explicit step presents a great challenge, for most of it is usually addressed as a mainly intuitive insight dependent process. How to command them to a computer (let us use computer here as the agent of information processing, either a computer, or perhaps, a design student for example) that is not able to do more complex tasks them basic (mathematical) functions?

Commands like "establish a relation between the building and those around it", or "provide room comfortable enough for this activity" must be broken down to simpler commands. Is this relation a colour one, a size one, a mimetic or contrast? In which direction? Of how much? "Those around it" means the adjacent neighbours, those up to three blocks away? "Comfortable enough" means just fit for the area needed for the movements of such an activity? Or how much more space?

Some more inventive computers can be able to fill the gaps needed, and then check if the solution achieved pleases who commanded it, eventually, through luck or trial and error, getting to a solution satisfactory enough. This is not the case of our computers yet, what means that describing a design procedure still depends on very specific and small steps. In this effort, many techniques were developed, among them adaptations from L-system (originally designed to describe plants growth) and Shape Grammar, both mechanisms of shape formation through sequential operations, theorised years before any computational implementation.

Coding Shape Grammar

Shape Grammar is a shape manipulation procedure developed by Stiny and Gips in the late 1970s, tracking back to earlier works from the linguist Chomsky on Generative Grammars. Basically, the original concept is that a language obeys rules of composition, so an idea is formulated into a certain general structure, and then replaces their general slots for kind-like words related to express that thought.

As we understood, what was kept for the translation to shape manipulation was the idea or rules of composition and sequence of shape manipulation/replacement in order to build up the final form. In this sense, the design procedure was understood as a sentence building process in a certain language (that of the object to be designed). Design is simplified and coded as, or in, the shape manipulation process, and our effort here was how to implement it computationally, as to say, structuring and describing an algorithm for Shape Grammars.

Many examples of Shape Grammars are paper drawing exercises, with few software not very well known in general. So, during the preparation phase we decided to implement our own Shape Grammar emulation for Grasshopper. To do so, we got back to some Stiny's initial texts[1, 2, 3] looking for elements to structure the definition. We identified a recurrent description that we organised into the triple ordinate –

G = (v, r, d)

- Where G is the grammar, v the vocabulary, r the set of rules, and d a set with the derivation, i.e., the sequence of rules to be applied. In Stiny´s classics, G, v and r are always mentioned. However, d appears only in a latent form, never explicit, be as markers, or as different set of rules for each stage of development, or as rules applicable to specific shapes that only appear after a certain rule is applied. Thus, we thought that it would be better to assign an independent set to the derivation sequence for a more coherent general structure, and also to allow for a more straightforward implementation.

The explicitation of the steps and parts led to a clear sight of the Shape Grammars. Our algorithm is understood as a protocol of concatenation between the three sets. Every step for the application of a certain Shape Grammar is described in this general structure, while each set is allowed independence in its inner definition, as long as the protocol of coordination is observed. It is a loop with v as input, applying the rule from the r indicated in d, accumulating the result back in v. Then d is a list with the names of the rules in the sequence they are to be applied, r is a set of Grasshopper definitions connected to a path selector acting as names for the rules, and v is another list with the accumulated shapes.

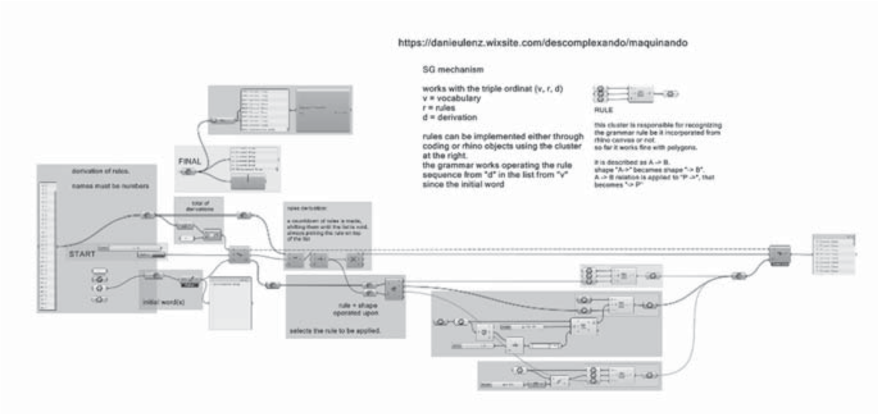

Figure 27.1

GFsysgen, overview.

While v and d are simple lists to store the initial and resulting shapes and the sequence of rules, r is more complex, holding most of the operation mechanism. For r, a generic algorithm was developed to dismiss extra expertise from the users about the grasshopper coding. It was organised in three steps: selecting the shape to operate on, apply the rule, put the result back in the shape list v. The selection of the shape to process is, by default, set to pick up from the top of the list, and after applying the rule, put the new shape on top of the list. A certain rule may, for instance, select more than one shape, or a specific one. The mechanism of rule application turned out quite simple, and is analogous to the analogical implementation:

a > b

- With a being the initial and b the resulting shape, or better, the shape that replaced the original. The algorithm takes in three inputs. Taking the first two, shapes a and b, it learns their relations of scaling, Euclidean transformations and replacement, to then apply to the third input p that is shape coming from the main loop. This rule relation can be established either through shapes resulting from Grasshopper coding or by drawing in the Rhino canvas, feeding the objects as breps to the inputs a and b. Making a new rule or modifying an existing one is just about drawing new objects and adding them as inputs to this part of the definition.

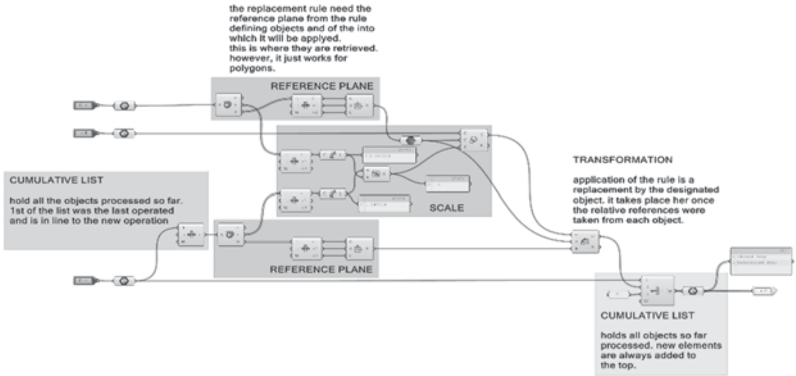

Figure 27.2

GFsysgen, rule definition.

As simple and powerful as this definition turned out to be, there are some holdbacks to point out. The developed algorithm presented does not have any code to recognise the shape it is dealing with, so it may happen to operate a triangle related rule to a square, for instance, which makes no sense. Another fault is that it cannot deal with recognition of shape emergence. We understand both are fundamental for a full emulation of a Shape Grammars application. Also, our definition does not work with markers as well, but the use of markers is more like a support for grammars, not being fundamental. As work in progress, those are issues to be addressed in following developments. The easy in operating the definition and some eventual simplicity on shapes used during the workshop made those issues, though fundamental, not problematic at all for the exercises.(1)

Workshop

Teams Experiences

For the workshop, participants all over Brazil were selected as to have different levels of formation, undergrad and grad students as well as professors. They were divided into groups so to have a balance between

(1) The Grasshopper definition can be downloaded under the post “Gramática da Forma, sistema generativo” at https://danieulenz.wixsite.com/descomplexando/maquinando.4

these categories in each one. The idea was to have at least one participant more experienced in parametric design in each group, though not mandatory. All participants were at least familiar with the idea of parametric design, even if with very little experience in Grasshopper coding.

The directed part of the workshop to Shape Grammar began with a theoretical presentation about its theory, followed by a few exercises. After that, this definition described above was presented and explained, as a directed Grasshopper tutorial. The emphasis, however, was much more in a code transparent use of the definition than on the explanation of the coding in itself. The structure and concept of the mechanism received much of the attention. After that, all participants were set to explore the definition in developing their own shape grammars. After that, in the next part of the workshop, each pair of teams being divided into the 4 techniques, were set to explore and develop a design occupying a space between 3x3x3m and 10x10x10m. The overview structure of the Shape Grammar definition turned out simple enough to encourage the teams to develop their own definition. At the end, they either turned back to using our definition changing only the rules, or to a very similar though shape/rule dedicated definitions but keeping the structure. In either case, many designs were explored before deciding for the final one. After the initial presentation and exercises, one of the teams developed a Shape Grammar relating music to facade (MF), while the other focused on shelters design (SD).

The MF team initially set to build a definition of its own to emulate the grammar, but after a few efforts, turned back to the original one. They assumed a poetic license to relate sound to musical notation to facade form, writing a code to translate the lyrics of a music they played live and them replacing it for a previous form on the facade. This exercise brought us to question the limits of shape grammar definitions. Is any graphic form applicable for a shape grammar? What kind of complexity may a shape have? The letters of musical notation can be understood as a shape? And what about the full facade design? Is there any limit for the shape transformation/replacement acceptable as a Shape Grammar? As exercises, those concessions were explored, but with not much answers to these questions yet. Meanwhile, the SD team dedicated to a more technical exploration. Based on the definition given, they actually developed their mechanism. Their investigation was how to implement a set of rules, and how to seek what kind of advantage this tool could bring. They started exploring rules independently, and after how to get them chained to get to a final design or another. They used simple geometric transformations, and afterwards taking note of the sequence used, got up a definition to generate a shelter. As a result, came up questions like, if this exploration is a step-by-step experimentation for one in a sequence design, what difference does it have from traditional design methods? In what part of the definition may one make interferences as to generate diversity? Can this diversity be automated? Does any sequence of rules deliver a coherent design?

Both teams ended up with a satisfactory design. The nature of the definitions led to a bit different procedure though. The music team withheld from a definitive design as much as possible, rather dedicating more energy in the procedures or rules and music-letters conversion. The shelter team explored a larger quantity of rules, testing their general effects and combinations. However, they decided earlier for the final general design, and started working on the combination of rules to achieve it making some explorations in parameters definition as well.

Conclusions

The different approaches of each team brought questions of different natures to the same subject. For sake of the exercise, and to arrive to a final design, they were more issued then addressed, leaving them as points that need further attention. This, however, did not keep us from having some intuitions and reflections over the matter. In fact, they team up with some speculations over the frame of the triple ordinate we designed, were identified a few potentials and questions, both technically and conceptually.

Beginning with those points brought about during the coding of the definition, it was clear to us where to address some of the issues not tackled in our work.

We identified that an emergence recognition mechanism is still to be developed. Rather than a true recognition, as it would imply a cumulative scanning for it, some sort of emergence can be implemented inside the rule coding. It would take advantage of the possible known results of the rules by the coder. It is also where one manipulates the hole list of shapes, so even the cumulative scanning can properly be done there, even if computationally costly. It might as well be a specific rule, to recognise the emergence of this or that shape.

As mentioned before, our definition does not identify what is the shape it is working with, so it may happen to apply an improper rule to it. As we understand, this shape recognition should be the kind of parametric shape recognition. Also, it is easier to develop inside the rule coding, but if one chooses, it can very well be part of the derivation mechanism. In this case, this mechanism grows in complexity, and a shape-based sequence can easily be achieved. It would identify the shape and then choose between the applicable rules.

This also makes clear that every degree of variation of sequence is to be encoded here. The derivation ordinate plays a fundamental part in Shape Grammar. Usually, Grammars are taught as shapes and rules, and derivation remaining rather obtuse or unclear, as if it could be just by chance. We understand all the randomness has to be incorporated at the derivation. It is necessary to point out that a full randomness probably leads to meaningless design. Some amount of randomness, though, can be used and still secure some meaningful design. In this case, the derivation set must be treated as a decision tree, with different paths encoded, and the randomness used to change between them, being or not shape oriented decisions.

Returning to the questions derived from the participants' works, the question about the complexity of the shapes dealt with seems to have a rather arbitrary answer. Though in the *Introduction to shape and shape grammar* the level of complexity Stiny deals with is rather simple, it does not exclude more complex ones. Rather, in *The Palladian Grammar*, Stiny and Mitchell are quite comfortable in replacing almost abstract shapes for much complex and symbolic ones. The essential mechanism of Shape Grammars seems to be the replacement, rather than a transformation of an original one. In this case, a symbolic grammar is also a shape grammar?

A more pragmatic question was proposed by the other group. What is the difference, and the advantage if any, of Shape Grammars compared to traditional design methods? As it seems, as a once in a time design, the design is still resulting from arbitrary decisions, and the construction of sequence and rules look as troublesome and time costly as the traditional drawing-based methods, though with speeded up explorations in cases where parametrization fit. Measurements related to design time should be made, and some quality measures accorded before one can be able to address this question correctly. Anyway, it is likely this might have a bigger difference, at least related to time, when a grammar is put to generate more than one design. If we understand time as one of the more addressable costs of the designing process, then maybe a generative system-based strategy, as the shape grammar is, can hope to drop the time cost for each unique design of the same system, and thus turn design more accessible.

References

1. George Stiny, "Ice-ray: a note on the generation of the Chinese lattice designs", *Environment and Planning B* (1977) volume 4, pages 89-98.
2. George Stiny and William Mitchell, "The Palladian Grammar", *Environment and Planning B* (1978) volume 5, pages 5-18.
3. George Stiny, "Introduction to shape and shape grammars", *Environment and Planning B* (1980) volume 7, pages 343-351.
4. https://danieulenz.wixsite.com/descomplexando/maquinando accessed in 28 February 2018.

II.4

"Classical" Generative Grammars

CHAPTER TWENTY-EIGHT

RE:9²GRID—FRAGMENTED PARTS AND THE UNIFIED WHOLE

GIACOMO PALA

Geometry and Abstraction

Composition has always been and always will be the main tool for architectural creation, which is, in turn, based on the use of geometry and abstraction. In this paper, I will discuss different ways of interpreting and using the grid, as well as collage and composing a "whole" alongside architecture's history. Finally, I will introduce a work I have developed in order to reconcile these different modes.

Geometry as Form

To start, it is worth looking once again at the now canonical studies of Rudolf Wittkower and Colin Rowe. In 1949, Wittkover exposed a single spatial type beyond eleven of Andrea Palladio's villas: a nine square grid.[1] In other words, he found a geometrical rule that guarantees the universal applicability of a design methodology. In this case, geometry becomes a type: a true *self-regulating body*, as argued by Greg Lynn.[2] Colin Rowe got even further than Wittkower. In his *The Mathematics of the Ideal Villa*, he even suggests that such a spatial type can be seen as a true universal system. In fact, what he found out is the presence of the same formal structure in two of Le Corbusier's buildings: Villa Savoye and Villa Stein. The geometrical definition of a formal structure is the type and the form of architectural thinking shared by every architect.

Form as a Discourse

Yet, what is the nature of such a grid? Some might argue that it is an abstract diagram, while others might argue that it is a formal type: a figure. Still, in order to enter this debate, we have to leave the realm of pure geometry and enter in the dimension of formal discourse. In this sense, we see that the grid is usually described as a device providing the maximum degree of abstraction.

Grids

This is how the story goes. The grid and the type have a long relationship starting in the late 18th century. At that time, architects started to first explicitly think in terms of formal methods. It was no longer enough to design according to classical language or its Mannerist and Baroque iterations. Architecture had to be founded through the development of methodologies. Abstraction and form became the fountainhead of architecture.

1. Disposition, Composition, Unity: these were the terms explicitly coined and unambiguously defined at the time. Disposition was the method used to assign to each thing its place and its use.[3] It was the almost deistic order of parts. Composition: the "part to whole" problem. Leon Battista Alberti had already defined the beauty of a building as the adjustment of all the parts constituting a whole, so that one cannot change it without disgracefully modifying the overall compositional harmony. Still, it was in this period that architects would have stressed the definition of the methods to achieve such beauty. Marc-Antoine Laugier, Jacques-François Blondel, Charles and Pierre-François-Leonard Fontaine, Georges Gromot, Julien Gaudet, and Quatremère de Quincy developed rules and methodologies to achieve such a beautiful beauty. Losing its metaphysical qualities, architecture became then a pragmatic problem. Alberto Pérez-Gómez would even define it as positivistic: "Once [architecture] adopted the ideals of a positivistic science, architecture was forced to reject its traditional role as one of the fine arts. Deprived of a legitimate poetic content, architecture was reduced to either a prosaic technological process or mere decoration".[4] Champion of this way of thinking, the master of rationalization: Jean-Nicolas-Louis Durand.

2. "Combine together the assorted elements, then move on to the different building parts and from these parts to the ensemble, that is the procedure to follow when one wishes to learn to compose; however, when composes, one should on the contrary begin with the ensemble, continue with the parts and finish with the details".[5] With these words, Durand described the modes of composition: architecture is now based on a method. Basically, as correctly written by Christopher C. M. Lee, Durand spent his whole career attempting to develop a method based on abstraction with the aim of developing universal laws and rules that would have been copied and adopted by other architects.[6] In order to do so, he worked on the concepts of "economy" and "utility" by simplifying architecture's language through the adoption of abstraction and types. In other words, architecture had to be composed and thought of as a mechanized system: the city is made of buildings; the building is made of parts; the parts are made of elements; each element is made of components; and each building is composed in accordance with axes, symmetry, centrality, and grids. Everything can become a type that can be applied if abstracted. Yet, in this method, we see a duality: the grid can become the abstract diagram on which one can pose types (Durand famously provided his students a specific grid paper in order to develop their projects), or it is, rather, a type itself: a figure to play with.

The Grid as a Diagram

Abstraction

Indeed, the grid can be seen as a diagram providing formal order and indexing. It is nonfigurative and abstract: almost absolute. It is a simple geometrical field that can be used to develop anything, from tables (Superstudio's tables) to complex cities (the colonial cities built by the Spanish in South America or Barcelona). In other words, as argued by Pier Vittorio Aureli, "the grid has no directionality, no expressivity, and supposedly no symbolic content: it is what it does, and in that sense, it claims for itself a formal logic of neutrality".[7] It is a way to develop and control complexity.

1. The grid became a true "myth" in modern architecture: a mechanism used to resist centralization and avoid any hierarchy between parts. Furthermore, this idea had a political mask. In Colin Rowe's words, "[the grid] insists that rank of parts of the building should be approximately equal; and, the staccato ordinance of the gridded structure being thus abundantly democratic, how can those almost imperceptible gradations which establish one part of a building as superior to the rest being introduced?"[8] Townscapes are made of grids (New York City), and projects have been developed through the use of grids: Ludwig Hilberseimer's visions, Mies van der Rohe's projects, and Le Corbusier's city for three million people stand as paradigmatic examples. For instance, when in 1940 Mies van der Rohe started to develop his project for the Illinois Institute of Technology, he used the grid with an unprecedented coherence. It framed everything: from the masterplan to the buildings' structures and facades in a sort of endless swapping of open and closed spaces. Furthermore, and even if in the realized project we see the application of a symmetrical rule, it is possible to argue that this building is the highest realization of a grid-like structure and a direct filiation from Durand's ideas. In fact, as Durand, Mies wanted to theorize an absolute architecture, based on methods that were as refined as they were simple. The grid is then proven to be a form of abstraction that allows the development of a sort of formlessness, thereby conceptually enabling the possibility of constantly reconfiguring the parts of a project.

2. One might correctly argue that this method would have taken architecture to one of its worst dead ends: boring cheap architecture justified on the basis of its rationality and grid-like genesis. Yet, there has been a phase in architectural history in which the homogenizing and abstract nature of the grid was taken to such an extreme that it was even used to define radical visions of alternative worlds. It is worth remembering Superstudio and Archizoom among these radical visions. With their "continuous monument", Superstudio invented an infinite object that cuts reality by providing spaces for living based on three-dimensional grid that constitutes volumes. Archizoom, instead, dissolves the functions of living and their technological components in a grid that is expanded in all possible directions: a flat, abstract, and endless surface providing space for human activities. This is the end of the story: the grid finally achieved the maximum level of abstraction and power. The grid finally became Generic and, deprived of any authorial quality, it can be adopted as a field of absolute abstraction.

Grid as Figure

What has been written until now is the "canonical" story of the grid. So canonical that, according to Pier Vittori Aureli, it can be synthetized as follows: Orders (in the classical sense), Composition (French theory), Plan (Mies and Hilberseimer), and Surface (Superstudio).[9] Yet, allow me to propose a continuation of such a story, or rather, an existing alternative. The narrative told until now seems to be missing another (and equally important) side of the story: the grid as a figure. In fact, going back to the famous text by Rosalind Krauss about the grid (entitled "grids"), we find two different notions of the grid in relation to its use and interpretations. Of course, the grid is anti-figurative; of course, it is geometrical and anti-narrative. Sure, the gird is a way to produce literality: things are abstracted and different from how they appear in reality. Yet, the grid, as such, is not just a form of abstraction, as it can become an object itself. The former way of thinking about the grid is called by Krauss as "Centrifugal", while the latter is "Centripetal". If the centrifugal is the idea that a grid is a geometrical structure that extends in all directions to infinity (as it happens in Mies or Archizoom), the second is quite the opposite:

> The grid is, in relation to this reading a representation of everything that separates the work of art from the world, from ambient space and from other objects. The grid is an introjection of the boundaries of the world into the interior of the work; it is a mapping of the space inside the frame onto itself. It is a mode of repetition, the content of which is the conventional nature of art itself.[10]

Grid is then a figure too, and architecture's history is plenty of examples, such as Theo van Doesburg, Le Corbusier, and Louis Kahn. They have all used the grid as a figure or, rather, the grid as an object, or as a type.

1. Still, the most obvious use of the grid as a figure happened in that period between the late sixties and late eighties and has been defined by Jacques Lucan as the *Formalism and Linguistic Paradigm*.[11] In this long period inaugurated by architects such as Aldo Rossi, James Stirling, and Hans Hollein, architects tried to redevelop a linguistic comprehension of the discipline: architecture is a language based on the composition of abstract elements, figures, and/or typologies. In other words, in front of the grid that had become the mainstream cliché of corporate building, architects were seeking for new "meaning" in architecture through the notion of language. Such a search for new meanings led the way for new formalisms and new ways of deploying narratives in architecture. Still, the formalism of these days was something radically different from that of Durand, Mies, or Superstudio. In fact, at this point in time, composition became a concept to toy with. The perfect example of such a difference is "deconstructivism". If architects like Van Doesburg or Louis Kahn have to be considered as formalists because they were funding their work on compositional rules, then they were also trying to develop new forms of coherences. In contrast, deconstructivism had in his definition a very postmodern nature: the language of modern architecture was a language one could toy with. Exactly when the postmodernists (or rather the PoMo architects) were toying with classical language, the deconstructivists were working on an ironic take on modern architecture. So, as Rem Koolhaas and Zaha Hadid were messing around with the language of constructivism, some architects were playing with the formal condition of the grid. The grid was no longer an order, but a figure.

2. The most famous architect who has been working with the idea of the grid as figure is Peter Eisenman. Eisenman's concern was about the understanding of the "formal system" of architecture. According to him, any building is based on a specific ideal form, in turn becoming a figure. For instance, in his rendition of Terragni's work, we can see an architect struggling with the representation of the formal system he used in order to design his buildings. Architecture then is literal and autonomous: it is first and foremost a matter of syntax. His houses are to be considered as the representation of form. In fact, if it is true that Eisenman defined his work as independent from signification, it is also true that it signifies the object itself by putting the compositional procedure adopted to design the buildings in front of our eyes. For instance, when talking about one of his houses (House VI), Eisenman says the following words: "the building is not an object in the traditional sense, not the end result of a process, but more accurately a record of a process, so that the process itself becomes the object."[12] The grid and the formal dispositions are the objects. In turn, the grid is the figure.

3. A work equally famous, but slightly different is by John Hejduk. Hejduk, famously worked with the nine-square grid problem as a proper figure enabling both the development of a literal space and as a way to teach students "to comprehend the relationship between two-dimensional drawings, axonometric projections and three-dimensional form".[13] Despite, as widely studied by Mark Linder, trying to translate the work of Gris and Mondrian (one of Hejduk's favourites) in architectural terms, we can look at Hejduk's use of the nine-square grid as an attempt to reconcile the spatial organization of a plan with the realist need of a domestic space. In other words, as Hejduk defined Mondrian as a realist (because he reinvented the real through his paintings), so we can argue that what Hejduk was trying to do was to reinvent domestic space through the means of abstraction.[14] For instance, in his House 7, we read a careful disposition of the interiors and the stairs in an abstract composition. The stair is combined with one of the interior walls: recomposing a square slightly asymmetrical that is dialogue with another square (the elevator) placed in the left-bottom square of the top right square composing the overall plan. The nine-square grid is used as a device to organize the internal space of the house.

RE:9^2Grid

It is here that my work immodestly starts by asking a question: if we can consider the grid as a figure, can we think of it as a device that externalizes the overall composition rather than locking it in a square or a cube? In other words, would it be possible to find a reconciliation between the "centrifugal" and "centripetal" reading mentioned by Krauss?

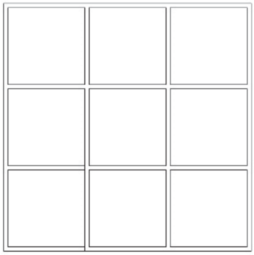

Figure 28.1

Nine-Square Grid. Diagram

The Fragmented Figure

In order to do so, it is worth referring to the most centrifugal logic for producing a formal consistency in a composition: the logic of fragmentation. Indeed, many architects would have argued that the grid was a figure, as how could they have generated complexity otherwise? By fragmenting the overall composition. In fact, as noticed quite beautifully by Robin Evans, as soon as we recognize a fragment of something, we have to deal with the origins of the piece.

> As soon as we identify something as broken, we become detectives of its history. What larger entity was it dethatched from? How did it end up in bits or, […] how are we to imagine it got that way?[15]

Of course, a fragment can be different. The megastructures of the 1970s have demonstrated that a building can be composed of an assemblage of units and components or, as argued by many recently, it is also possible to develop projects defined by "discrete parts".[16] Yet, if one starts from the point of view of a figure (shall we say the Nine-Square-Grid), fragmentation is quite a useful way of dealing with complexification. Even more if, as I have tried, one is seeking for a tension between internal order and centrifugal complexity.

In order to describe the notion of the fragmented figure is useful to mention a parable mentioned by Evans: *The Parable of the Elephant*.[17] In this parable, there are several people who cannot see (according to Evans they are in a cave, while other sources say that they are blind) and have the task of describing an elephant by means of touch. In doing so, none of them are able to construe the whole of the elephant, because they only know a small part of it. According to Evans, this story describes the poetics of Cubism. Following his reasoning we can argue that we find ourselves in front of a "fragmented figure": a fractured homogeneity through which we can see the overall silhouette, yet fragmentary. But the story has indeed deeper roots:

1. As the grid finds Durand's work as its paradigmatic axiom, so the "fragmented figure" finds it in the work of one of his contemporaries from another country: Sir John Soane. Of course, there are precedents to Soane's work (Richard Payne Knigth's and John Vanbrugh's architectures), but his work is unprecedented for its radicalism and strength. More specifically, Soane's project for the Bank of England (1788–1893) stands as a particularly interesting example. This project can be seen as a sort of "seamless collage"[18] in which Soane is able to reconcile the need of order and the aim of complexity in a plan made of figures, with one next to another. To cut a long story very short, since then we have seen the use of collage techniques an infinite amount of times: from Viollet le Duc to Le Corbusier; from the constructivists to the deconstructivists, up to the passionate and touching craziness of architects such as Günther Domenig, Eric Owen Moss, and Zvi Hecker. Then, the question underlying the definition of this work—which still is at a very early stage—is, how can we reconcile fragmentation and unity? Is it possible to do it avoiding the—by now boring—rhetoric of the "digital" and its less interesting expressions, such as parametricism?

Contradictory Homogeneity

To give an answer to this question, I have tried to work on the remix of these two former strategies: both had to be visible and independent, yet mixed and one in continuity with the other. Unity and fragmentation. RE:9^{2}Grid: remix of the grid. Yet, we should also acknowledge that even the operation of remixing has a longer story. A story that finds its peak in the work of Robert Venturi and in what has recently been popularized as the "difficult whole".[19]

In his seminal book, *Complexity and Contradiction in Architecture*, Robert Venturi defines the need of theorizing an architecture that is not composed as a well-designed whole. Yet, such an achievement, according to Venturi, must be reached by defining a whole: a difficult whole, "because the whole is difficult to achieve".[20] Generalising this concept, we can say that the difficult whole can be defined as a kind of contradictory tension between order (whole) and complexity (fragments). In this sense, if considered as such ("the old tradition of enclosed and contrasted space"[21]), we can consider the work of Louis Kahn, James Stirling—whose work is defined by Manfredo Tafuri as "controlled bricolage"[22]—or even Giovanni Battista

Piranesi in this way. Furthermore, we can consider the overall debate regarding urban design as a "figure ground" problem or the use of open and closed *pochés* as forms of contradictory homogeneity. This concept seems to be particularly interesting for many reasons today, including

1. It allows us to go beyond both the abstraction of the grid and that of the fragments.

2. After the digital—after the fluidity of a complex formalism in which the whole becomes a "spline-dominated, curvilinear style"[23]—architects seem to only be interested in "parts" as a new sort of fragmentation. The difficult whole might be helpful for the definition of forms of coherences by looking once again at our past, which, in this case, is fragmented homogeneity.

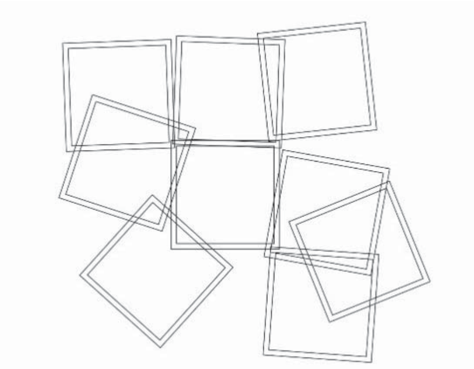

Figure 28.2

Fragmented Nine-Square Grid. Diagram.

My work has been about the Nine Square Grid problem, which is intended as a figure. As seen, this "diagram" is usually used to organize a space in a centripetal way: it is the boundary of a space and its nine divisions frame the interior plan. How is it possible to produce complexity through this figure? An easy answer is by means of fragmentation. In order to do so, I have given a random rotation to each of the nine squares relative to the same centre of rotation; in this case, it was placed in the centre of the plan. As we can see, the result is the pure fragmentation of the parts composing a figure. Each fragment comes from a more organized whole. The grid is decomposed and broken into bits and pieces, each being one of the nine squares composing the overall drawing.

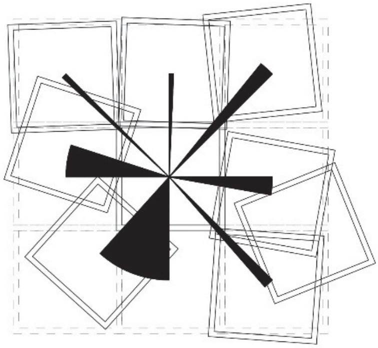

Figure 28.3

Formal Method. Diagram.

Once this operation was completed, I developed a way to connect the different parts. In order to do so I used simple connections made of arcs. The arcs were developed by interpolating the different intersections between the lines composing the nine squares.

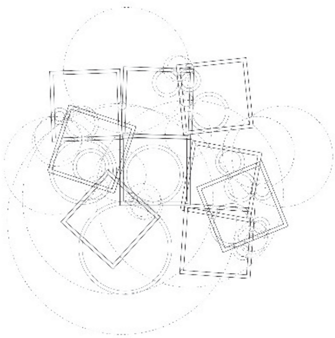

Figure 28.4

The Connections Between the Parts. Diagram.

Quite simply, the resulting diagram is a negotiation between linear drawings and curvilinear elements that connect the different parts by smoothing the corners and slickly connecting the various elements. There is no discretion; everything is explicit. There is a whole that is visible and yet the parts are separated from one another. The method is simple, but the result starts to include a bit more of a contradiction. Squares and curves, and corners and circles, have a crush one another and from their formal intercourse a new whole is developed. Once this first result was achieved, I overlaid the original figure of the grid on the result of the interpolations, in the attempt to obtain a difficult whole or, rather, a "fragmented homogeneity": the parts all similar among themselves, but connected differently and related to an overall diagram. As a sort of layering of different formal properties, this composition aims at having a sort of double meaning: once as a classic nine-square grid, and once as a fragmented grid. Like the image of the duck that some see as a rabbit, this design is aiming for a contradiction. Is it this or that? It is both and, indeed, both the formal logics come from the same origin. It is then a sort of interpolation of conditions that starts with the same sort of conceptual origins, which is developed in two different shapes. Yet, the differences, once they are fused, constitute a coherence, which is—in its details—contradictory. Without wanting to sound arrogant and hoping to not embarrass myself, I have been attempting to apply the logic used by Soane in his project for the Bank of England: different figures that deform each other, which transforms some of their characteristics, while maintaining their original features. The starting figures—the grid—deprived of its logics of abstraction, is considered as an object instead.

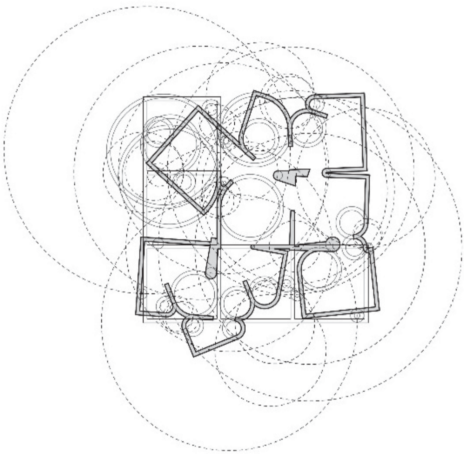

Figure 28.5

Over Imposition of the Starting Figure. Diagram.

Finally, the result is a kind of "fragmented homogeneity": the parts and whole are both visible, at the same time related and independent from each other. Yet, one question comes to mind: can architectural designed be reduced to the adoption of a method?

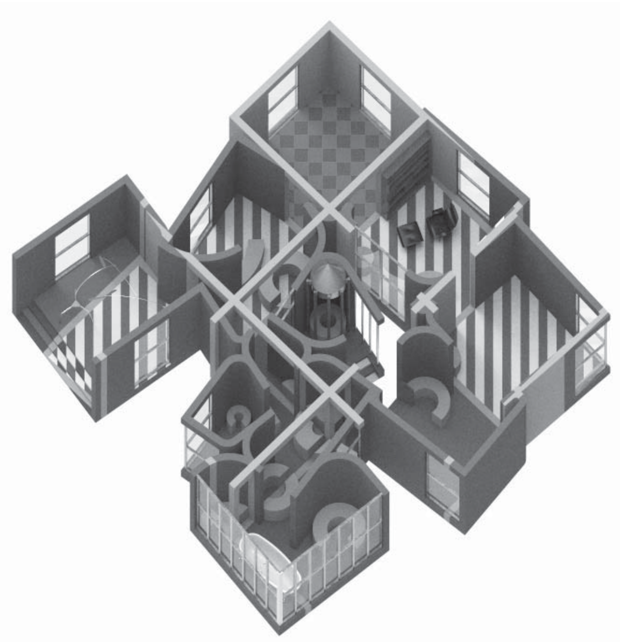

Figure 28.6

RE:9²GRID.

No, it cannot. True, the method is fundamental, but it is not all. It is very fundamental, but not the main characteristic of architectural design. How should we deal the notion of domesticity? What is the relation between abstraction and formalism with the realism of function? Which one is elevating the other? Architecture is not just about formal methods. It is about the negotiation between formalism and function, between ideas and practical considerations. And all of these constitute discourses and ideologies. The same form can be the expression of different discourses of paradigms. When talking about form, one has to consider aesthetics as well. Are the colours neutral and devoid of meaning? Maybe. Yet, they embody "characters".

Architecture is also a matter of aesthetics, politics, function, and discourses. If so, then, there is a final question that still has to be discussed: is it possible to use form to represent them? How?

The answer probably is the project.

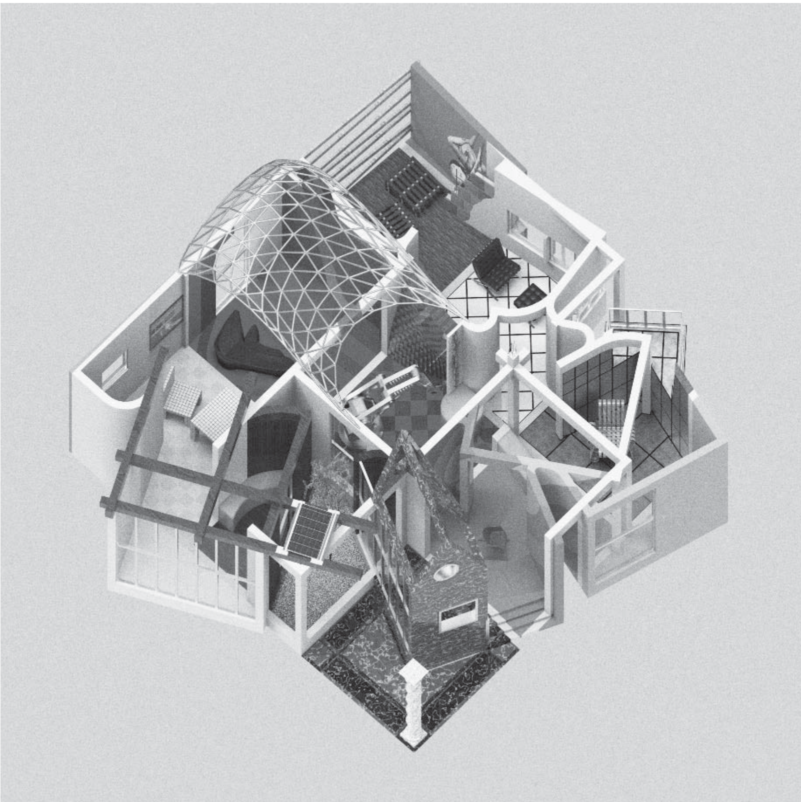

Figure 28.7

RE:9²GRID: The Rooms of Discourses.

References

1. Wittkower, Rudolf. "Palladio's Geometry: The Villas," in *Architectural Principles in the Age of Humanism*. New York: W. W. Norton, 1962.
2. Lynn, Greg. "Multiplicitous and Inorganic Bodies", *Assemblage*, No. 19. Cambridge: the MIT Press, Dec., 1992. p. 33.
3. De Quincy, Antoine-Chrisostome Quatremeère. Dictionnaire, I, "Disposition", p. 530.
4. Pérez-gómez, Alberto. *Architecture and the Crisis of Modern Science*. Cambridge: MIT Press, 1983. p. 11.
5. Durand, Jean-Nicolas-Louis, Prècis, Volume I, Paris, 1819. Quoted in Jacques Lucan*, Architecture and Theory in the Nineteenth and Twentieth Centuries*, Oxford: Routledge Taylor & Francis, 2012 p. 39
6. See, Christopher, C. M. Lee, "The Deep Structure of Type in Durand's Method". In Pier Vittorio Aureli (edited by), *The City as a Project*, Berlin: Ruby Press, 2013. pp. 170–212.
7. Aureli, Pier Vittorio. "More and More About Less and Less: Notes Toward a History of Nonfigurative Architecture", in *Log*, No. 16. Spring/Summer 2009. p. 9.
8. Rowe, Colin. "Neo-Classicism and Modern Architecture II" (1956–57), in Colin Rowe, *The Mathematics of the Ideal Villa and Other Essays*. Cambridge, MIT Press, 1976. pp. 150–151.
9. Aureli, Pier Vittorio, *More and More About Less and Less: Notes Toward a History of Nonfigurative Architecture* (quoted) [10] KRAUSS, Rosalind, "Grids", in October, Vol. 9. summer, Cambridge: MIT Press. 1979. pp. 60–61.
10. See, Lucan, Jacques, op. cit., pp. 523–542.
11. See, Lucan, Jacques, op. cit., pp. 523–542.
12. Quoted in Kristina Luce, "The Collision of Process and Form: Drawing's Imprint on Peter Eisenman's House VI", *Getty Research Journal*, No 2. Chicago: The University of Chicago Press on behalf of the J. Paul Getty Trust. p. 125.
13. Hejduk, John. *Mask of Medusa*. New York: Rizzoli, 1985, p. 35.
14. Hedjuk, John "In a Mondriand painting, reality is conceived, reality is presented, reality is realized. All are one in the same thing". 1980. Quoted in Mark Linder, *Nothing Less Than Literal* Cambridge: MIT Press, 2004, p. 190.
15. EvanS, Robin, *The Projective Cast, Architecture and its three Geometries*. Cambridge: MIT Press, 1995. p. 56.

16. I refer to the work of architects such as Daniel Köhler, Gilles Retsin, José Sanchez, or Casey Reas.
17. Evans, Robin, *The Projective Cast, Architecture and its three Geometries*, Cambridge: MIT Press, 1995, p. 58.
18. I thank David Ruy for his introduction to this term at one of his lectures at the University of Innsbruck.
19. For more on this topic, see Kersten Geers, Jelena Pančevac, and Andrea Zanderigo (eds.), *The Difficult Whole: A Reference Book on Robert Venturi*, John Rauch and Denise Scott Brown (Zurich: Park Books, 2016).
20. Venturi, Robert, *Complexity and Contradiction in Architecture*. New York: The Museum of Modern Art Papers on Architecture, 1966, p. 88.
21. Idem., p. 88.
22. Tafuri, Manfredo, *The Sphere and the Labyrinth, Avant-Gardes and Architecture from Piranesi to the 1970s*, Cambridge, MIT Press, 1978), p. 269
23. Carpo, Mario, *The Second Digital Turn. Design Beyond Intelligence*, Cambridge: MIT Press, 2017, p. 64.

CHAPTER TWENTY-NINE

WILL DRONES HAVE A ROLE IN BUILDING CONSTRUCTION

NUNO PEREIRA DA SILVA, SARA ELOY

Introduction

This paper intends to explore the hypothesis that robotic technology can add value to the construction industry. Taking into account the use of robotic elements in other industries such as naval, automotive, and computer components, it is questioned here how these technologies could be used for the building construction industry and what would change in this industry by such a use.

The robotics technology has changed the method of production and the final products in several industries. In fact, industries, such as naval and automotive, have embraced robotic construction and their operating modes. Therefore, the final products have changed considerably. Our goal is to explore the possibilities of robotic technology considering the assembly part of construction, both with robotic arms and drones.

Robotic arms in the architecture industry are used mainly to digitally fabricate by subtracting but there are some worldwide experiences of using them for the assembly of construction elements; however, this use is rare and limited to experiments carried out at purely university level, which have only been applied on few occasions in practice.

The use of drones in the construction sector has increased considerably in recent years, mainly due to its uses in 3D scanning and photogrammetry. In these cases, drones fly over the areas that will have an intervention and carry cameras, video cameras, or sensors in order to collect data from the sites. The use of drones to assist the assembly of construction components has made much smaller advances than a similar one with robotic arms. This has also been limited to a few experiments carried out by universities, which seek to explore how this technology can be used to build actual buildings.

Experiments undertaken at ETH Zurich by a team of Gramazio Koehler Architects in order to explore "flight assembled architecture" and "aerial construction" with drones and with robotic arms; "informed wall", which was also by Gramazio Koehler; and the "on the bri-n-ck" by Ingeborg M. Rocker from Harvard University are very good examples of the use of such technologies.[1, 2]

This paper is divided into five sections. We will start by analysing the impact that robotic construction had in other industries, such as automotive, naval, and shoe making. In the second section, we address the current state of the art of robotic construction in architecture by describing the technologies involved, the experiments undertaken, and the opinion of the international experts. Section three describes the conceptual design of an experiment, as well as its underdevelopment, and in the last section we discuss the work and conclude.

New Technologies in Industry

The automotive industry has been the paradigm of the usage of brand-new concepts, since Henry Ford applied the concept of assembly line in the production of his famous vehicles for the first time. This concept, which was developed by Frederick Taylor (1856–1915), breaks down complicated tasks into simple ones, by measuring the minimal amount of time required for each task. This process forced the workers to follow those tasks while putting their own living conditions and needs on hold. At the beginning of the 1960s, robotics were introduced in the industry and now this technique has been perfected so that robots can execute specific functions, such as welding, painting, fusing, and assembling pieces; this has led to lower production costs.[3]

The *Lexus* factory is the current prime example of robotic usage. In it, the robots in the assembly line create and connect all of the pieces until its final product, with the quality check being the only activity performed by man.[4] Due to their use of technology and robots, the automotive industry is considered to be one of the most advanced fields;[5] in fact, during 2013, 70000 new robots were installed in many factories, increasing worldwide production by 90 million units.

Just like the automotive industry, the naval industry has constantly been at the forefront of the use of technology for the construction of larger vessels.

In this industry, robotics have been applied in four tasks: welding, painting, riveting, and the assembly of large pieces during construction.[6] In contrast to the automotive production, the naval industry, due to the size of some vessels, cannot work on an assembly line; instead it works by collecting blocks produced in outsourcing and assembled them at the shipyard. In the industry of recreational crafts of smaller proportions, the process of construction only differs from the automotive due to the fact that the vessels must stay put at one site during the whole process, forcing the robotic arms and the workers to move sequentially in an assembly line parallel to the vessels. Some producers use robotic arms to reduce construction time and human imprecision. According to their sources, the total control of geometric robotic construction allows the creation of vessels with perfect aerodynamics.[7]

Also, in the production industry of computers and their components, the replacement of workers with smart machines has taken place; it now uses an assembly line in which the intervention of men in the manufacturing of the final product is not necessary.

In 2011, Foxconn, the biggest enterprise of manufacturing in electronic components and computers in the world with more than a million workers, installed 10000 robots (foxbots) capable of making simple tasks, such as assembling, spraying, and welding. Ever since these events, foxbots have been replacing workers and increasing the volume of production.[8]

Also, smart robots are being developed in the shoemaking industry for companies like ADIDAS. They use 3D technology, which reduces the need for human workers. This aids the complex creation of shoes, thereby increasing their production and customization posibilities.[9]

It is nevertheless essential to mention that, in the premium sector, the tendency for robotization has not been as favourable. Many brands are betting on handmade aspects adding value to their product due to exclusivity (Fionda and Moore, 2009). As an example, Mercedes-Benz has been developing new models that are exclusively hand-made, thereby reversing the current phenomenon of using robots instead of humans on assembly lines.[10]

New Technologies in the Construction Industry

Drones and Robots

The Robotic Arm (RA) is a robot that functions much like a human arm, as it is able to function autonomously, or as a part of a more complete robot. The RA is a programmable manipulator, composed of rotational or linear segments that control the precision of their movements.[11] On the extreme end of the RA, there is usually a tool which is able to move, position, and manipulate objects; this could potentially be milling, cutting, or through a tube to deposit material. In the naval industry, the RB can execute tasks in ship hulls, such as electronic components, in a faster and more versatile fashion than the human hand. Also, in the automobile industry, the RA is used in the assembly line, improving the managing of time consumption and precision.[11, 12]

Drones are unmanned aerial vehicles. They are manually commanded through remote control, travelling under real-time human control, or programmed by using integrated systems of digital control, such as sensors, radars, and GPS.[13]

Military drones were primarily used in aerial platforms, which is why they were designated as UAV (Unnamed Aerial Vehicles). The first UAV, Havilland DH82B from 1935, was piloted by "servo-operated controls" and regularly used as a target. Nowadays, UAVs have been slowly substituting manned aircrafts.[14] In Afghanistan, UAVs have been used for acknowledgement and recognition of terrorist targets.[14] On land, drones have been used in Syria to replace the tanks in the defence of Russian bases, and are expected to replace other armed systems thus bearing less casualties, even though many ethical and deontological problems will arise.[15]

Civilly, drones are used in research during rescue missions, mapping, photographing, and even in the film industry. They also serve purposes like material deliveries in hard access zones and, in commercial aviation, monitoring of traffic, meteorology, and even driving cars. Drones usually have three dimensions: miniatures, medium sized, and large. The first are used as indoor amusement (hobby), the second (c.15x15cm) are used outdoors mostly to film and photograph, and the last ones (c.30 a 40cm) can fly outdoors without prerequired conditions, as seen in the Amazon project, which grants the delivery of packages up to 2kg.[16] The manually commanded drones reach a distance of up to 1.5km, while the Export System can reach up to 50km and 200m high, and 50mph speed; they are able to fly between 5 to 40 minutes, depending on their batteries, tasks to execute, speed of wind, and weight of the shipment, which can vary from 1kg to 20kg.[17]

Case Studies

In this section, two examples of robotic construction developed by a team of Gramazio Koehler Architects at ETH Zurich. The projects *Flight Assembled Architecture*[1] and *The Aerial Construction*[18] will be analysed.

During 2012, Gramazio Koehler and the robotic engineer Raffaello D'Andrea programmed drones capable of lifting and assembling thousands of bricks in the FRAC centre in Orleans. The project, *Flight Assembled Architecture*, was a pioneer in the assembling of pieces by drones. A structure with 6m high by 3m in diameter was built, with 1500 polystyrene's parallelepipeds (weighting around 100g and measuring 10x30x15cm[1]). The project intended to verify the feasibility of the construction of buildings by drones. Four drones were necessary, each one of them possessing servo-powered pins that cut a hole through the brick and hold it during the flight, a blueprint, a foreman, and a construction team. It was verified that the faster the flight occurred, the less external disturbances, such as turbulence and collisions, occurred and it also led to a smaller error margin. In the case of an inferior speed and a softer landing, the error margin was higher.[18]

In 2006, in ETH Zurich, the *Informed Wall Project* was developed, which was led by professors Gramazio and Kohler with the collaboration of postgraduate students. Each student conceived a project to pursue the goal of building distinct brick walls by using robotic arms to test their architectonic potential. In this experiment, students had to use a robot with 6 axes with an intervention area of 3x3x8m and capable of building architectonical components at a real scale. The robot needed to be able to construct a space using different materials, processes, and construction shapes with no exogenous interferences, able to reach any point in the tri-dimensional space, and able to execute all the tasks predicted by the Edeffector programme.[2] In the experiment traditional bricks were used. A claw was attached to the robotic arm in order to grab, lift, and place each brick in its correct place. It was also necessary to develop a computer script capable of translating the CAD data in coordinates by using the MAYA software. With the combination of software and the chosen material, many wall prototypes were produced. The conclusion was that the robotic arms can be used in a simple way in repetitive tasks with simple geometries by quickly placing bricks with a minimal error margin. The team concluded that in order to execute more complex geometric shapes, a bigger investment in software and hardware is essential.[2]

The Opinions of the Experts

To help the discussion of the future of robotic assembly, direct testimonies from some of the most relevant protagonists in this area worldwide were obtained: the architect, Fabio Gramazio, a pioneer in robotic construction and responsible for the creation of a robotic Lab for architecture research "Laboratory for Architecture and Digital Fabrication", in ETH Zurich; Tobias Bonwetsch, a researcher in the ETH Zurich Robotic Lab and co-founder of the ROB Technologies company; and José Pedro Sousa, co-promoter of the OPO'Lab project, co-founder of the architecture practice ReD, Research+Design, and professor in Universidade do Porto.

Many questions were posed to these specialists with the goal of obtaining their opinion on the future of robots in architecture. Gramazio's opinion was that the current robotic technology can already be applied in construction. In his developed experiments, the necessity for the existence of a system of sensors and a system of independent controls for the usage of drones in construction was established as a precondition. Regarding the processes of conceiving architecture, Gramazio stated that, due to the proximity of the robot's emergence, we can only speculate on the impact of robotics in architecture, even though we do acknowledge, through history, that the new technologies have consistently transformed the form of thinking and acting. Gramazio considers this technology to be disruptive and that it will only slowly enter the construction industry due to the massive cost difference. Gramazio predicts that its utilization will only happen in zones with difficult accesses, e.g., underwater. Gramazio also stated that a hybrid system, in which the human and the robot work together, will most likely be attainable. He also believes that the intensive use of this technology in the future is nothing but pure speculation and a 50-year advanced prediction is very difficult to do. Bonwetsch shares the same opinion, adding that this technology may reduce work-related accidents and its introduction will also affect businesses economically, socially, and aesthetically on the expected final result. Pedro Sousa is also of this opinion; further adding that robotics may already be applied on the construction of pre-made elements in controlled environments.

An Experience with Drones

In order to understand the advantages and the complexity involved in using drones in the construction process, three conceptual experiments were developed that will be put in practice in the following months. Each one of the three experiments hold a higher grade of complexity and intends to demonstrate different investigation hypothesis. The first of the three described experiments constitute the theoretical basis of the following two. The first experiment consists of the construction of a brick tower, the second is the composition of a flat vertical brick wall, and the third consists of the assembly of a geometrically complex brick wall. All of the described experiments consist of the construction of objects through the piling of elements using drones. With this goal in sight, we chose a simple construction where patronized elements, such as clay bricks, are assembled.

The experiences were performed in a controlled environment, preferably indoors through technologies that can provide a complete mapping. In order to do so, it is essential to provide a space covered by sensors much like a tridimensional grid, in which any point in its space corresponds to specific coordinates.

The following equipment is essential for the previously explained experiments:

- Two professional drones, with claws attached capable of carrying up to 1 kg bricks, or adapted commercial drones: DJI, 3D Robotics, or Parrot.
- A tablet with an Android system.
- Digital and tridimensional drawing software (e.g., Rhinoceros, Maya, 3D Studio max, or Revit).
- Drone control software.
- Coordinate control sensors for indoor action (beacons, a proper location with a source of wi-fi with resource to triangulation, on-board systems with autonomous navigation, collaborative systems, with many drones, data fusion in the many software, drone sensors, and the localization systems as previously mentioned).
- Brick dispenser.
- Bricks.

The first experiment (Figure 29.1) envisages a construction using two drones of a vertical wall with overlapping bricks, which are only secured by gravity. A circular route defined in a specific type of software enables a drone to be directed towards the brick dispenser, while the other places a brick in the predetermined coordinates.

The dispenser found at a specific location places a brick in the exact same coordinates every time. The drones are placed on a table, from where they depart and land to rest, alternately flying towards the dispenser. While the first drone displaces towards the dispenser, grabs the brick, carries it to the construction coordinates, lands, and lets go of the brick, the second starts flying towards the dispenser and performs the same route as the first one.

At the end of the sequential placing of the six bricks, the drones return to the starting table. The full process is controlled by a software in a controlling computer, showing in real time the construction process and the drones' routes.

The trajectories of the drones must be previously planned and constantly corrected in order to minimise possible brick placement errors, as exemplified in the experiments in the Interactive Learning Project, at ETH Zurich by Raffaello D'Andrea, who corrected several errors after identifying them.

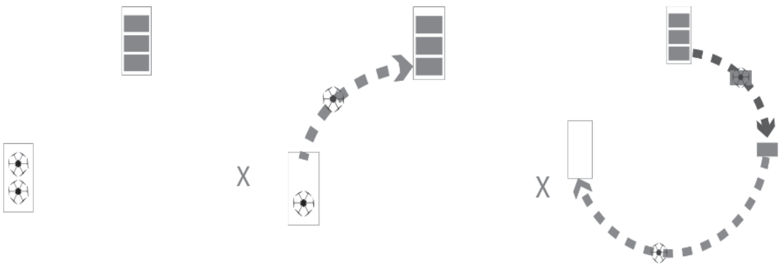

Figure 29.1

Schematic representation of the building route.

The second experiment (Figure 29.2) consists of a built a flat vertical wall made entirely out of bricks assembled in a traditional way and only fixed by gravity.

Figure 29.2

Schematic representation of the tower using 6 bricks: Experiment 1, elevation and plant.

The goal of this experiment is to compare the construction process of a traditional brick wall by a bricklayer with another built by drones, comparing bot time spent and final quality. On the first model, the construction coordinates X and Y were always the same, and only the coordinate Z was changed. In this second model, the bricks would be placed in changing Y and Z coordinates, keeping the axe X.

The third experiment (Figure 29.3) consists of the creation of a curved wall, with several rows of brick spaced between it. This experience allowed us to compare the precision obtained by the drone assemblage in a complex geometry design. In this model, each brick has a specific coordinate in order to create the wall's curvature, as well as leaving a two-quarter space between them for the upper rows to have a sitting area on top of two bricks. Each one of the bricks is placed according to its coordinates in Y, X, and Z. For the construction of a wall with this sort of complexity, it is essential to perfect and calculate the trajectory of each drone in order to place the bricks with minimal error in their exact position.

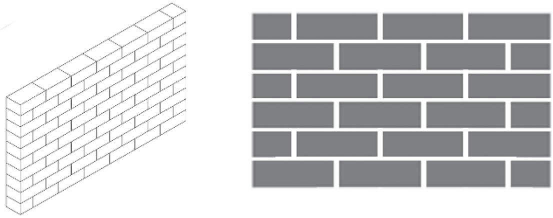

Figure 29.3

Schematic representation of a traditional linear wall: Experiment 2.

Discussion and Conclusions

After analysing the pioneer industries on the implementation of robotics in production, we can identify that the construction industry has resisted the introduction of robotization. The construction process is still slow, imperfect, and highly expensive, depending, almost entirely, on human work. This situation may be altered with the introduction of construction processes that include robotization, mainly with the aid of drones and robotic arms. The use of this technology may, similar to what happened to other industries, come to alter the construction industry, allowing it to execute low-cost standardized houses, for example.

The possibilities that these technologies bring may allow the construction industry to *i*) build complex shapes nimbly and with little to no errors; *ii*) promote the usage of new materials by the newly-acquired flexible assembly; and *iii*) idealize architecture in a new way, thereby enabling the use of free shapes. The robotic arms and the drones may be used simultaneously, in different tasks, in order to assemblage a building as a whole, to reduce human error, and to speed up the building process.

The two experiments with drones were successful, namely in the construction of tensile structures (through tessellating) and the construction of a brick wall (through deposit). Nowadays, this technology is available but greater financial investment and will are necessary to make this process grow and be applied in practice. Both drones and robotic arms allow a faster construction, with lower costs, which enable the industry to explore new shapes and materials, as well as introducing a new way of thinking that may re-project architecture.

Interviewing three architects that work in the areas under analysis proved to be very relevant. Even though this technological evolution is developing quite fast, the experts' opinion is that it will be difficult to apply it in the near future to the construction industry. They stated that this slow introduction is the result of the high cost of the drone application that may only be justified in extreme cases, such as submarine construction or in dangerous situations. To these architects, the introduction of these technologies will only begin with the application of a hybrid system, a man-machine, due to the fact that the technology is currently in development, and not capable enough to respond to *in situ* situations. Nevertheless, Pedro Sousa says that this technology can be applied during pre-fabrication in controlled environments. However, it is clear that any predictions about drones are pure speculation.

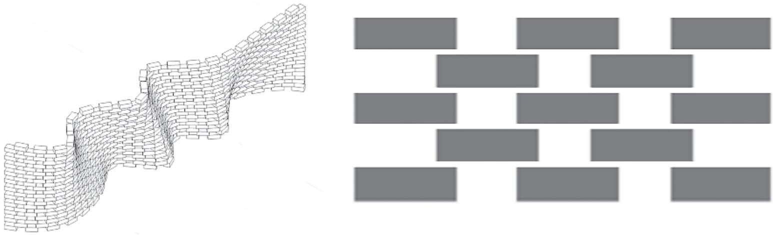

Figure 29.4

Schematic representation of the wall pattern created: Experiment 3.

References

1. ETHZ. *Flying Machine Enabled Construction*. (2017) Idsc.ethz.ch. Retrieved 2 May 2017, from http://www.idsc.ethz.ch/research-dandrea/research-projects/archive/flying-machine-enabled-construction.html.
2. Bonwetsch, T. Kobel, D. Gramazio, F. Kolher, M. 'The Informed Wall applying additive digital fabrication techniques on architecture'. *ACADIA 2006: Synthetic Landscapes Digital Exchange*, (2017) 491–494.
3. Ahlborn, Tom. 'Industrial robotics in the automotive industry'. *Industrial Robotics*. (2015). Retrieved December 10, 2016, from: https://www.bastiansolutions.com/blog/index.php/2015/09/17/industrial-robotics-automotive-industry/#.WHkgG2NFvJM.

4. Friedman, Thomas. The Lexus and the Olive Tree. New York: Anchor Books (2000).
5. Jurgens, Ulrich. Malsch, Thomas. Dohse, Knuth. Breaking from Taylorism: Changing Forms of Work in the Automobile Industry. Inglaterra: Cambridge University Press (1993).
6. Rooks, Brian. Robot welding in Shipbuilding. MCB University Press (1997) pp. 413–417.
7. Bavaria Yachts. Quality: Persuasive power of sailing yachts | Bavaria Yachts. (2017). Bavariayachts.com. Retrieved 29 May 2017, from https://www.bavariayachts.com/en-uk/bavaria/quality/sailing-yachts/.
8. Davidow, William. Malone, Michael. 'What Happens to Society When Robots Replace Workers?' (2014). *Harvard Business Review*. Retrieved December 10, 2016, from: https://hbr.org/2014/12/what-happens-to- society-when-robots-replace-workers.
9. Patten, Brigg. 'Robot shoe factory a new trend of the future?' (2016). *Automation*. Retrieved December 20, 2016, from: http://www.automation.com/automation-news/article/robot-shoe-factory-a-new-trend-of-the-future\.
10. Rico, Carolina. 'Fábrica da Mercedes substitui robôs por pessoas'. *Noticias ao Minuto*. (2016). Retrieved Janeiro 10, 2017, from: https://www.noticiasaominuto.com/economia/546316/fabrica-da-mercedes-substitui-robos-por-pessoas.
11. Harris, T. *How Robots Work*. *How Stuff Works*. (2017). Retrieved 12 February 2017, from http://science.howstuffworks.com/robot2.htm.
12. Anona. What is a robot arm? (2017) Robots.com. Retrieved 10 February 2017, from https://www.robots.com/faq/show/what-is-a-robot-arm.
13. Rouse, M. Drone (unmanned aerial vehicle, UAV) - TechTarget. (2017). Retrieved December 2017, from http://internetofthingsagenda.techtarget.com/definition/drone.
14. Pereira Da Silva, N. A ética do militar no século XXI. *La Etica Del Soldado Del Siglo XXI*, *3*(1) (2014).
15. Joyner, James. The US Military's ethics crisis. Retrieved December 2017, from Atlantic Council/org/Blogs/newsatlanticist, 2014, p. 6.
16. Amazon. Amazon Prime Air. (2017) Amazon.com. Retrieved 31 May 2017, from https://www.amazon.com/Amazon-Prime-Air/b?node=8037720011.

17. Dronelli, V. 8 Heavy Lifting Drones [April 2017 Edition] (2017). | Available on Amazon. DronesGlobe.com. Retrieved 26 May 2017, from http://www.dronesglobe.com/guide/heavy-lift-drones/.
18. Mirjan, A. Gramazio F. Kohler, M. Augugliaro, F. D'andrea, R. Architectural fabrication of tensile structures with flying machines. *Green Design, Materials and Manufacturing Processes*, 513–518. (2013) Available at
http://flyingmachinearena.org/wp-content/publications/2013/augCRC13.pdf.

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She graduated in architecture from Delft University of Technology in 1989. She has worked for various architectural firms, including Karelse van der Meer Architecten and ArchitectenCie. Since 1999, she has been a lecturer in architectural design at Delft University of Technology, and, since 2009, she has been the editor of the journal OverHolland. In 2014 she obtained her PhD at Delft for a dissertation entitled Kwartiermakers in Amsterdam: ruimtelijke transformatie onder invloed van stedelijke instellingen, 1580–1880, a commercial edition of which has been published by Vantilt. Her current research focuses on the role of urban institutions, such as universities, in more recent transformations of Dutch cities.

Filipe Brandão | *Information Sciences, Technologies and Architecture Research Centre*

Architect (FAUP, 2006) with an Erasmus year at the University of Oulu, postgraduate degree in Digital Architecture from CEAAD (Advanced Studies Course in Digital Architecture), jointly organized by ISCTE and FAUP. PhD candidate at ISCTE-IUL/ISTAR-IUL with the thesis Cork Re-

Wall: Computational Methods of Automatic Generation and Digital Fabrication of Cork Partition Walls for Building Renovation. Won a research grant from Amorim Isolamentos and a merit grant from ISCTE-IUL ISTA for the development of the PhD research. Collaborated with ANC-Arquitectos and Grupo3 Arquitectura. Independent practice since 2007, with two years' experience as Vice-Director of JFS Angola and Site Manager of Sonamet Headquarters in Lobito, Angola. Co-founded PARQUR architecture collective in 2012.

Franklim Morais | *Opo'Arch Project, Porto Arts Higher School*

He is an engineer and researcher at Laboratório de Investigação em Arquitectura (Laboratory for Research in Architecture), Escola Superior Artística do Porto (ESAP/Porto Arts Higher School). His research focuses scientific fields of architectural space configuration, accessibility and visibility analysis, and hardware and software systems for intelligent management of buildings, urban spaces and "smart" environments. He is a civil engineer, and he has a PhD in Electronic Engineering. He is Professor of the MArch at ESAP, where he lectures on building structures and advanced technologies. He also develops his professional activity as an engineer and researcher on his own company.

Giacomo Pala | *Institute of Urban Design, University of Innsbruck*

He is a PhD candidate studying under the guidance of Peter Trummer at the University of Innsbruck. More specifically, he is conducting a research about formalism and its relation to narrative and time (parachronism), using as a departure point Piranesi's work. Pala has taken part in different research programs at Genoa's University, including the "parametric representation" program during the academic year 2015/2016. He has published papers and participated to international conferences. In 2014, he won the "DiaStízein Prize". In 2013, he co-founded Burrasca: an independent cultural association. He co-edited some of this organisation's magazine.

Gonçalo Castro Henriques | *Faculty of Architecture, Rio de Janeiro Federal University, LAMO*

He is a Full Professor at Rio de Janeiro Federal University (FAU-UFRJ) and coordinator of the Laboratory for Models and Digital Fabrication (LAMO-UFRJ). PhD Architect (FAUTL, Lisbon 2013), MArch (ESARQ-UIC, Barcelona 2004), Architect (ESAP Porto 2000), Erasmus student (TUE Eindhoven 1998). Currently he is the Vice-President of the Ibero-American Society of Digital Graphics (SIGraDi). Architect, Researcher and

Professor on the integration of generative processes (algorithmic and parametric design, scripting), with simulation and digital manufacturing (CAAD-CAE-CAM). He thrives to connect the academy, research and industry introducing algorithmic design and digital fabrication. Currently focused on the development of responsive systems through the merge and intertwine of areas such as architecture, computation and biology.

Isadora Tebaldi | *Federal University of Rio de Janeiro, LAMO*

Isadora Tebaldi is a student of Architecture and Urbanism at the Federal University of Rio de Janeiro. She attended a year of academic exchange at Kingston University in London, England. She is currently a researcher at the LAMO (Laboratório de Modelos e Fabricação Digital/Laboratory Models and Digital Fabrication) associated with the postgraduate program PROURB.

Janet Hetman | *Department of Architecture, Roma Tre University*

Architect, PhD Candidate in Architecture and Urban Design and Teaching Assistant at Roma Tre University. She has worked in several design offices and as researcher in projects promoted by the DAD and the research centre CRD-PVS of the Polytechnic of Turin. Her main field of interest is urban inhabiting and its socio-spatial manifestations; her research is on urban device of co-presence, investigated by the disciplinary integration between architectural and urban design, and urban sociology. She is currently a visiting scholar at LAA [architecture Laboratoire et Anthropologie] LAVUE ENSA Paris La Villette.

Jarryer de Martino | *Federal University of Espírito Santo*

Javier Poyatos Sebatián | *Polytechnic University of Valência*

PhD Architect and Professor. Coordinator for Theory of Architecture at the Universidad Politécnica de Valencia. Director of the Department of Architectural Composition, Universidad Politécnica de Valencia. He has been Secretary and Deputy Director of the Department of Architectural Composition, Universidad Politécnica de Valencia, and Deputy-Director of Quality and Deputy Director of Culture, Quality, and Image of La Escuela Politécnica Superior of Alcoy, Universidad Politécnica de Valencia. He also leads the research team “Innovación y Excelencia en la Configuración de los Entornos Humanos” of the Department of Architectural Composition, Universidad Politécnica de Valencia. He has organised several international symposium and seminars related to architecture. He has various publications on theory and criticism of architecture and the city. Among the buildings in Offices of Banesto Bank and Commercial Gallery Jorge Juan, both in Valencia.

Jorge Vieira Vaz | *Opo'Arch Project, Porto Arts Higher School*

He is an architect and he develop his research within the Architecture and Technology Group, the Laboratory for Research in Architecture at Escola Superior Artística do Porto (ESAP/Porto Arts Higher School). He is Scientific Coordinator of the research project OPOArch Formal Methods (funded by PT2020, NORTE2020 and the European Union). His scientific production is on taxonomies, ontologies, and classification systems in scientific fields on architecture and construction technologies, including virtual design to construction project and BIM methodologies. He holds a Diploma de Estudios Avanzados (DEA/Diploma in Advance Studies) from Escuela Técnica Superior de Arquitectura de Valladolid (Architecture Higher Technical School of Valladolid) at the Universidad de Valladolid (University of Valladolid). He has a Master's degree in Architecture from Poznan Technical University and a Diploma in Architecture from Faculdade de Arquitectura da Universidade do Porto (Faculty of Architecture, University of Porto). He is Senior Lecturer of the MArch at ESAP. He develops his professional activity as an architect with design projects in different parts of the world.

Kerstin Sailer | *Space Syntax Laboratory, Bartlett School of Architecture, University College London*

Kerstin is Reader in Social and Spatial Networks at the Space Syntax Laboratory at UCL's Bartlett School of Architecture. She is a sociologist at heart, bur trained as in architect in Germany, where she completed her Diploma in Architecture (Leibniz University of Hannover), as well as her PhD thesis "The Space-Organisation Relationship" (Technical University of Dresden). A Knowledge Transfer Partnership (KTP) between UCL and Spacelab Architects brought her to London in 2006. In this project, she developed a new and intensively data-driven workplace consultancy service for Spacelab. Apart from a short stint as visiting PhD student in 2005, she joined UCL in 2006 as KTP Associate, became a Teaching Fellow in January 2009, was appointed Lecturer in October 2009 and was promoted to Reader in 2016.

Larissa Gomes | *University of Campinas*

Laura Roldão Costa | *Trás-os-Montes e Alto Douro University/LR-Arquitetura Paisagista, Lda.*

Laura Roldão Costa is Landscape Architect with a PhD in Landscape Architecture. She is currently an Assistant Professor of Landscape Architecture at Universidade de Trás-os-Montes e Alto Douro (UTAD). Her research areas include Forest Sciences and Design, Urban Ecology, Urban Design and Planning, Participatory Methods of Planning, with a special interest in the simulation and evaluation of the development of vegetation in the urban space.

Luísa Cannas da Silva | *CERIS/Instituto Superior Técnico, University of Lisbon*

Luísa Cannas da Silva is a post-doctorate researcher at IST. She obtained an integrated master's degree in Architecture (2011, IST) with the dissertation "University Atlas of Lisbon Metropolitan Area", and a PhD in Architecture (2017, IST) with the thesis "Campus as a City, City as a Campus—a morphological approach to university precincts in urban context". She is a licensed architect, and has practiced in both P.R. China (2011–2012) and Portugal. Her main research interests have been related to educational facilities, and innovative learning environments, mostly focusing on the higher education context, ranging from a macro-scale of understanding the knowledge infrastructures as urban elements to micro-scales of space-use analysis. During her PhD, she developed research expertise in the area of spatial analysis within the theoretical and analytical framework known as "Space Syntax". She was a member of the organizing committee of the 11th International Space Syntax Symposium. She has organized diverse outreach programs ranging from Athens courses (short term duration courses offered to students from different universities located abroad), technical workshops, and team building events at the research centre, CERIS's, Open Days. She has also engaged in several international workshops, namely, "Open space systems" at the University of Florida, 2014, and the "Smart[er] Cities" research program, a joint initiative by the University of Bergamo and the Graduate School of Design at Harvard University.

Luiz Amorim | *Federal University of Pernambuco*

Titular Professor of the Department of Architecture and Urbanism, he coordinates the Laboratory of Advanced Studies in Architecture (lA2) and the Research Group on Architectural and Urban Morphology. He is a researcher 1B of the National Council for Scientific and Technological

Development (CNPq), editor of Thésis journal, member of the Space Syntax International Steering Committee and on the editorial committees of the journals Arquitextos, The Journal of Space Syntax (JOSS), Revista de Morfologia Urbana, and FRBH Publishing House.

Mafalda Toscano | *CERIS/Instituto Superior Técnico, University of Lisbon*

Maria Júlia Jaborandy | *Pernambuco Catholic University*

Meta Berghauser Pont | *Chalmers University of Technology*

Associate Professor in Urban Design and Planning and leads, together with Lars Marcus, the Spatial Morphology Group (SmoG). Her research focus is Urban Morphology specialising in the quantification of urban form. She developed the Spacematrix-model which shows the relation between urban density and urban typologies and its performativity. Develops urban analysis on how urban form can support or cancel out certain social processes or Urban Ecosystem Services, such as social segregation, pollination, and biodiversity.

Nicola Marzot | *TU Delft*

Nicola Marzot has taught as a lecturer at the Faculty of Architecture of Firenze, Ferrara, and the Faculty of Engineering of Bologna, where he obtained his first PhD in Building and Territorial Engineering in 2000. Since 2009, he has been Assistant Professor at the Department of Architecture, Chair of Public Building, TU Delft, where he defended his second PhD in Architectural Composition in 2014. Nicola focuses on the theory and method of architecture and urban design, in close relation to Urban Morphology and Building Typology. He is member of the Public Building group at the Department of Architecture, Delft University of Technology. Nicola is also a practicing designer and the co-founder of Studio PERFORMA Architettura + Urbanistica in Bologna, Italy, mostly focusing on building vacancy and waiting land regeneration processes.

Nicolle Prado | *Universidade Federal do Rio de Janeiro*

Nuno Pereira da Silva | *ISCTE-Lisbon University Institute*

He is a student in the 5th year of the Integrated Master's in Architecture at the Instituto Universitário de Lisboa (ISCTE-IUL). The first part of his architecture education was completed in Universidade Lusófona de Humanidades e Tecnologias (ULHT). He has always been interested in using new technologies in his architecture practice as a student and exploring the impacts of these new technologies.

Olindo Caso | *TU Delft*

Olindo Caso graduated from the University of Naples, Faculty of Architecture. Since 1990, he has been active at the Delft University of Technology, where he achieved his PhD in 1999. Presently, he is part of the Complex Projects group at the Department of Architecture, and coordinates the research group, Architecture and the City. Olindo engages in master education and research activities. Main research interests relate to the architecture of the infrastructure, in particular the cultural infrastructure and the infrastructure of mobility. He is the author of (international) publications, among which *Architettura contemporanea: Olanda* (Milan: Motta, 2009) and *ATLAS. Makerspaces in Public Libraries in the Netherlands* (Delft: TU Delft Open, 2019). Olindo has several years of experience in the design practice in Italy and The Netherlands.

Osman Sümer | *Istanbul Technical University*

Patrícia Alonso | *Universidade Federal da Paraíba*

Adjunct-Professor of the Department of Architecture and Urbanism. PhD student in Architecture and Urbanism from the Postgraduate Program in Architecture and Urbanism at UFPB, who is currently completing part of her PhD studies at the Spatial Morphology Group (SmoG) at Chalmers University of Technology, Sweden.

Patrick Janssen | *National University of Singapore*

He is Associate Professor in the Department of Architecture at National University of Singapore. He holds a Master's degree in Architecture (AA Dipl.) from the Architectural Association in London, an MSc in Cognitive Science and Intelligent Computing from Westminster University in London, and a PhD in Architecture from Hong Kong Polytechnic University in Hong Kong. Prior to coming to Singapore, he held an appointment at the University of Melbourne, Australia. His research interests include parametric design methods, performance-based design, and design optimisation.

Paulo Renato Pellegrino | *São Paulo University*

Associate Professor at the Faculty of Architecture and Urbanism School, University of São Paulo (USP). He is vice-Coordinator of LABVERDE where he develops research on topics such as green infrastructure, urban waters, landscape ecology, and urban resilience; and projects that explore infrastructural functions of landscapes at various scales and locations, with the parameters of performance measures, feasibility, and aesthetic quality for application in landscape design and planning methods.

Pedro Engel | *Faculty of Architecture, Rio de Janeiro Federal University, LAMO*

Architect, graduated from the Federal University of Rio Grande do Sul, Porto Alegre, Brazil, in 2002. Has practiced architecture with a focus on ephemeral structures. Since 2009, he has been a Professor in the Federal University of Rio de Janeiro (UFRJ) dedicated to first year studios in the Department of Analysis and Representation of Form. He has been dedicated to investigations in architectural pedagogy, design methodology, and representational methods through Master's and PhD research in PROARQ-UFRJ. In 2016, he joined the research groups LAMO (Laboratório de Modelos) and TEMPU (Teoria, Ensino e Metodologia do Projeto Urbano), both at the PROURB-UFRJ, performing research relating pedagogy, the city, and architectural form.

Petros Koutsolampros | *Space Syntax Laboratory, Bartlett School of Architecture, University College London*

Petros studied Architectural Engineering at the National Technical University of Athens before graduating from Adaptive Architecture and Computation MSc at The Bartlett. Initially under a Knowledge Transfer Partnership (KTP) between Spacelab and UCL, and currently as a PhD student in the Space Syntax Laboratory, Petros is exploring patterns of human behaviour in office buildings and their relationship to the properties of space. Petros is a Tutor on the Architectural Computation MSc programme, teaching on the Introduction to Programming and Body as Interface modules. He is interested in spatial analysis through statistics and simulation, human-computer interaction, graphics and video games. He is also a regular contributor to the development of the open-source spatial analysis software depthmapX

Reem Shurush | *Technion – Israel Institute of Technology*

Ricardo Massena Gago |*Faculty of Architecture, University of Lisbon, CIAUD*

He is an architect and researcher with a PhD in Biogeometry. His mains interests are related with the geometrical narrative of the biological structures, ecological shape, generative and parametric design processes, and biomaterials. His current work focuses on the development of a design process able to transfer the biological identity to human structures (architecture, design, and graphic design). The goal is to provide architects and designers the possibility to manipulate the design process through a biological perspective. Using this drawing method, he developed proposals for architectural pavilions, luminous installations, and geometrical patterns for women's apparel.

Ricardo Mendes Correia | *Information Sciences, Technologies, and Architecture Research Centre*

Ricardo Mendes Correia graduated with a MSc. in Landscape Architecture (UL 2018) and a five-year degree in Landscape Architecture (ISA-UTL 1997). Currently, he is a Research Assistant at the Information Sciences, Technologies, and Architecture Research Centre (ISTAR-IUL) at ISCTE-IUL in Lisbon, Portugal. Ricardo has worked for 20 years with Digital Design and Geographic Information Systems and has a degree in this area (IST-UTL 2001). Through his work, Ricardo acquired experience in the areas of Virtual Reality and Augmented Reality.

Roberto Cavallo | *TU Delft*

Roberto Cavallo is an Associate Professor and Head of the Architectural Design Crossovers group at the Department of Architecture of the TU Delft. He finished his PhD at the TU Delft in 2008. Currently, he is a member of the departmental Research Steering Team. In 2018, he was elected council member of the European Association of Architectural Education and he is founding member of the Architectural Research Network ARENA. He has been the Director of Education for the Faculty of Architecture and the Built Environment of TU Delft. Roberto has an extensive experience in organising and coordinating international workshops, symposia, conferences, and exhibitions. He built up an outstanding reputation in terms of academic leadership that goes beyond the TU Delft Faculty of Architecture. Registered as a licensed architect, he also has several years of experience in practice.

Roberto D'Autilia | *Dipartimento di Matematica e Fisica, Roma Tre University*

Physicist, he thought Mathematical and Statistical Method for the Urban Planning at the Department of Architecture, University Roma Tre and now teaches Parallel and Distributed Computing at the Department of Mathematics and Physics at the same University. His research is addressed to the modelling urban structure and growth, sustainability, pedestrian flow, optimal use of the space, relationships between the city and the country, and artificial intelligence.

Romulo Krafta | *Federal University of Rio Grande do Sul*

Bachelors in Architecture and Urbanism from the Federal University of Rio Grande do Sul (UFRGS), Porto Alegre, Rio Grande do Sul, Brazil (1973), Master's in Urban Design from Oxford Polytechnic Oxford Brookes University (1982), and Doctorate in Urban Science from University of Cambridge (1992). Postdoctoral Fellow at the Centre for Advanced Spatial Analysis (CASA), University College London, England (2001) and at the Federal University of Rio de Janeiro, Brazil (2013). He is currently Full Professor at the College of Architecture, Federal University of Rio Grande do Sul (UFRGS). He is a tenured professor in the Graduate Program on Urban and Regional Planning (PROPUR–UFRGS).

Rudi Stouffs | *National University of Singapore*

He is Associate Professor in the Department of Architecture at National University of Singapore. He holds an MS in architectural engineering from the Vrije Universiteit Brussel, an MS in computational design, and a PhD in architecture from Carnegie Mellon University. He has held previous appointments at the School of Architecture at Carnegie Mellon University, and is the Chair for Architecture and CAAD at ETH Zurich, and the Chair of Design Informatics at TU Delft. His research interests include computational issues of description, modelling, and representation for design, mainly in the areas of shape recognition and generation, and building/city information modelling and analysis.

Rui Colaço | *Superior Institute of Technology, University of Lisbon*

He is a material engineer with research topics ranging from nanotechnology to corporate social responsibility. He holds a MSc. degree in Materials Engineering from University of Lisbon/Superior Institute of Technology and an MBA from Open University of Portugal. He has professional experience in engineering and business development in Europe, Asia, and Africa.

Sara Eloy | *Information Sciences, Technologies and Architecture Research Centre*

She is an Assistant Professor at Instituto Universitário de Lisboa (ISCTE-IUL) where she teaches Architectural Computer Aided Design, Computation and Research Methodologies. Her areas of research include CAAD, shape grammars, and the possibilities of using them in real design scenarios, immersive virtual and augmented reality for the design process, and the analysis of the building space namely considering space perception, and space syntax. She graduated in Architecture (FAUTL) and has a PhD in Architecture (ISTUL) where she investigated a transformation grammar-based methodology for housing rehabilitation. She is the Director of the Information Sciences and Technologies and Architecture Research Centre.

Sérgio Mendes | *Research Laboratory in Architecture and Design, Porto Arts Higher School*

He holds a degree in Architecture from Escola Superior Artística do Porto (ESAP/Porto Arts Higher School) and a PhD from Escuela Técnica Superior de Arquitectura de Valladolid (Architecture Higher Technical School) at the Universidad de Valladolid (University of Valladolid). He is Assistant Professor in Constructions and Technologies within the MArch at the ESAP. He is also a member of ESAP Scientific Council. He is Director of Laboratório de Investigação em Arquitectura e Design (LIAD/Laboratory for Research in Architecture and Design) at ESAP. As LIAD Integrated Researcher, he developed scientific activity in the area of Construction and Technologies, and he was Principal Researcher of the project ESAP/2015/P16/DARQ, funded through the ESAP Projects 2015 competition. He has worked as a professional architect and he collaborated with Alcino Soutinho during 1987–91. He was a finalist candidate for the National Prize for Urban Rehabilitation in 2015.

Sofia Garza Vargas | *Faculty of Architecture, Universidad Autónoma de Nuevo León/ULHT*

Sociologist, Master's in Urban Affairs, student of the Doctorate in Urbanism. Faculty of Architecture and Urbanism. School of Communication, Architecture, Arts, and Information Technology. ULHT.

Susanne Komossa | *TU Delft*

She graduated from the Delft University of Technology, Faculty of Architecture and the Built Environment. In 1991, Susanne started her own firm Komossa Architecten BNA in Rotterdam. As an Associate Professor of Architectural Design, she coordinates, teaches, and lectures in the master programs of the Public Buildings group. In 2008, Susanne Komossa obtained her PhD at TU Delft. She is the co-editor and author of the book "Atlas van het Hollandse Bouwblok" (Thoth, 2003). Its English edition, "Atlas of the Dutch Urban Block", was published in 2005. He also edited and published "Color in Contemporary Architecture" (Uitgeverij SUN, 2009).

Tasos Varoudis | *Space Syntax Laboratory, Bartlett School of Architecture, University College London*

Dr Tasos Varoudis is a Senior Teaching Fellow, professional architect and computing engineer with research focusing on hybrid architecture, computational analysis, and machine intelligence, and has a long teaching experience with UCL, AA, and RCA. Since 2011, he has been instrumental in the spatial and architectural computation research for the Space Syntax Laboratory where he develops new methodological and computational innovations combining spatial data-driven models with machine learning and agent-based models. He is the lead developer of depthmapX'spatial network analysis software: the most widely used tool in research and practice. He currently runs Research Cluster 14 (RC14) at the MArch Urban Design, and he is part of UCL's new Urban Dynamics Laboratory funded by a 4m EPSRC grant.

Teresa Valsassina Heitor | *CERIS/Instituto Superior Técnico, University of Lisbon*

She is Full Professor of Architecture at the University of Lisbon, Instituto Superior Técnico (IST). She obtained a first degree in Architecture (1982, Escola Superior de Belas Artes de Lisboa, PT), a Master's degree in Urban Design (1984, Joint Centre for Urban Design, Oxford Brooks University, UK), a PhD in Territorial Engineering (1997, Technical University of Lisbon, Instituto Superior Tecnico, Lisbon, PT), and a habilitation in Architecture (2007, University of Lisbon, Instituto Superior Tecnico, Lisbon, PT). Currently she is the chair of Architecture at IST and Director of CiTUA (Center for innovation in Territory, Urbanism, and Architecture), a new multidisciplinary R&D Unit housed at IST. She has been teaching post- and undergraduate students in Architecture at IST for the past 20 years.

Ugo Santana | *Estácio do Ceará University Centre*

Victor Sardenberg | *Leibniz Universitaet Hannover*

He holds a post-graduate Master of Arts with a specialization in Architecture and Urban Design from the Städelschule Architecture Class, Frankfurt am Main, and a professional Bachelor's Degree in Architecture and Urbanism from Mackenzie University of Architecture and Urbanism, São Paulo. He is an Associate Researcher in Digital Methods in Architecture at Leibniz Hannover University and he has taught computational tools and digital fabrication in workshops including at The Architectural Association Visiting Schools, UFRJ, UFMS, Hochschule Dusseldorf, and Städelschule.

Ye Zhang | *National University of Singapore*

He is an Assistant Professor in the Department of Architecture, School of Design and Environment, National University of Singapore. He holds both a BArch and MArch from Tsinghua University, China and a PhD in Architecture from the University of Cambridge, UK. His principal research interest is in urban morphology, specifically the formative process of street layout in Asian cities and the performance of built form and its relationship with urban design.