FORMAL METHODS IN ARCHITECTURE AND URBANISM

Edited by David Leite Viana,
Franklim Morais and
Jorge Vieira Vaz

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INTRODUCTION

FORMAL METHODS IN ARCHITECTURE AND URBANISM

DAVID LEITE VIANA, FRANKLIM MORAIS AND JORGE VIEIRA VAZ

Formal Methods in Architecture and Urbanism is the new concept this book is introducing.

Formal Methods

Formal methods is a concept very well established in computer and information sciences and technologies, and means roughly the use of theoretically driven techniques, expressed in languages stemmed from mathematics. With that designation or another, formal methods have applications in many human activities. Technologies were always eager for theory, especially since the 17th century. Linguistics and even literary studies are other fields that make steady use of the concept of formalization. Even mathematics is prone to formalization. Since the 17th century, and apace since the 19th, what had already been born formal a few millennia before is growing more and more formal. Number theory, calculus, logic, set theory and later developments such as modern algebras, language theory, and category theory are setting formal layer over formal layer in math theories. Rather than trying to reach a goal of formal ideal, formalization is a never-ending process of theoretical deepening. In addition, with the mathematical approach, it is a process of theorizing the theory.

It is not the scope of this introduction to make a broad analysis of characteristics or advantages of formal methods. Nevertheless, two features will be noticed, each with a little help from a short allegory.[1]

The first:

> *Paul, the mason who knows geometry, has to lapidate several stones of intricate shape to fit together. He produces each stone independently in the yard, and then goes to the church to place it.*
>
> *Peter, the tinker mason, had the same job. He made the first and laid it. He made the second and, surprisingly (to him), the stone did not fit. The priest did not let him adjust the piece inside the church. He went to the yard for retouching. Then he tried to place it again. At the fifth try, the stone still did not quite fit, but, at least, it did not fall. It was the right time to move on to the next stone. The sun has set by now and Peter is still working on his church. Paul, meanwhile, is at Peter's house.*

In general, we may say that the use of formal methods brings great advantages to human actions on his natural and social environment. The problems are at first solved in idea and only then are they practiced in reality. The formalization tries to make certain that the solutions for the problems of reality are produced mentally in such a manner that ensures simultaneously their greatest possible adequacy and the least test time in direct confrontation with reality. For example, language theories acquired formal parameters of analysis, such as expressivity, finiteness, completeness, simplicity, complexity, determinism, decidability, soundness, recursion, that enable us to meta-theoretically ensure the desirability of the use in the set of problems that the given language has to deal with.

The second:

> *Some years later, Paul and Peter (now a mason as skilled as Paul) are still working together, producing stones for the church. A formal method is not necessary to deduce that a friendship has not grown between Paul and Peter. They do not even talk to each other. But when one of them takes a new piece to the church, it beautifully fits with the stones of the other.*

---

1. The editors would like to apologize for the unbearable lightness of the next text. It is a little homage to recently deceased Umberto Eco, who so many times softened arid speech with brightening results.

Formal methods try to ensure perfect communication instruments between the acting agents. That is even more useful nowadays, when those agents are not only humans but rely on artificial digital tools with their own languages.

Formal Methods in Architecture and Urbanism

The use of formal methods in architecture is very old: formalized geometry has now twenty-five centuries, and has been applied extensively in construction. Even earlier achievements, such as the pyramids of many different ancient cultures, cannot be understood without considering the possibility that their builders exercised some incipient geometry. Since the development of natural sciences, in the 17th century, many other formal methods have been deployed in architectural *ars et scientia*.

Starting with structural theory and expanding to thermal, hydrous, acoustic, chemical behavior of buildings, the formalization of architectural methods has become an obvious reality. Such reality led even to professional differentiations with historical significance. When the architects of the Renaissance detached from the construction masters, they took most of the mathematics with them. Now it seems that the architects have renounced math, leaving it to the engineers. Nevertheless, current practice in the domain of the built environment still attributes to architects the overall consideration of the social and human desiderata.

Two achievements led to the improvement of the use of formal methods in architecture. At first, since the 19th century, sociology and psychology were established as theoretical sciences as well. Secondly, the already mentioned developments led mathematics from the ancient privilege of quantification to a broad treatment of very abstract set of entities, such as qualities, change, structures, abstract spaces that adjust particularly well to architectural languages.

Formal Methods in Architecture and Urbanism: The Book

Formal Methods in Architecture and Urbanism is the result of editing work on the proceedings of the 3rd Symposium Formal Methods in Architecture (Porto (Portugal), 2015).

The papers presented in this volume are contributions to the progress of formalization in architectural methodologies. From the millennial geometry to current shape grammars, several formal approaches to architecture and urbanism will be presented, with their different points of view, different fields of application, different grades of abstraction and formalization. The aim is to look at the potentials and objectives of these formal methods, both those on the horizon as well as those already accomplished, their successes but also their problems.

The intention is to promote the use of formal methods in the creation of new explicit languages for problem solving in architecture and urbanism. These problems range from representation, to theory, critique, production, communication, etc., never ceasing to see architecture and urbanism as technological activities and well as artistic ones.

The more historically established areas of application of mathematical sciences, such as traditional geometries or mathematical developments connected to engineering, are left somewhat outside the focus, without forgetting the deep connections these scientific bodies of knowledge establish with the new formal methods. Many of these formal methods have a level of development that requires the existence of established academic communities, with their own specialized forums.

We could define the concept of *Formal Methods* by their matrix: they make intensive use of the repertoire of languages coming from mathematics. However, a new concept cannot limit itself to the sum of a bunch of dispersed elements with parental affinity. The several pieces must belong to some special structure. The 3rd International Symposium Formal Methods in Architecture, more than an attempt to deepen each specific field, is above all about finding points of convergence. This is not limited to a possibly interesting abstract integration of different areas of research, but mainly to advance the multiple crossings between several methods, whose fertility has already been proven.

A certain dialogue with semi-formal and even informal methods in current use will be visible as well, to deepen the discussion on aesthetic and ideological controversies that surround the possibilities and reach a formalization of architecture and art. Although not patent in this book, and as in previous symposia, some contributions were applications of formal methods on fields other than architecture, like literature, music and the fine arts, in as much as they may be useful for architectural application.

The Structure of the Book

Human behavior has an evolutionary path, from reality to reality, through the mind. Mental processes recognize the circumstances of reality, elaborate knowledge, evaluation and decision procedures, and then command human action on the world, creating new realities. Knowledge starts with sensory acquisition of the concrete reality, passes a long process of abstract organization, and goes back to the concrete of reality, not any more as a sensory concrete, but now as a conceptually structured concrete. This book tries to follow this same path, applied to architectural activities.

Part I deals with formal tools for data acquisition and first steps in gathering, treating and organizing information. Two well established methodologies deal with these purposes.

One of them is BIM (Building Information Modelling). BIM is an activity rather than an object, a human activity that involves logical thinking, digital entities and a large sort of specific software, with a strong impact in building design and construction activity. The transition to BIM, however, is not a natural progression from CAD (Computer Aided Design), because it involves a paradigm shift from “drawing” to “modelling”—a virtual model consisting of relationships between entities, organized into an object—based on inheritance hierarchy. Technological and market trends are good predictors of the short-term future in this field, and it is opportune to analyze and discuss how BIM will be developed in different, yet correlated, areas like VDC (Virtual Design to Construction) and in peripheral hardware linked to building, prefabrication, assemblies, functions of construction management connected to ERP (Enterprise Resource Planning), ontological and semantic searching and compatibility of BEMs (Building Entity Models) to multiple platforms, IPD (Integrated Project Delivery), automated checking for code conformity and constructability to support Lean Construction, improved import and export capabilities using protocols like IFC (Industry Foundation Classes) and parametric 3D technical catalogues from manufacture industry, the setting up and development of National Building Standards in connection with Green Building, LEED (Leadership in Energy and Environmental Design) or BREEAM (Building Research Establishment Environmental Assessment Methodology) and expanding the scope and discipline-specific BIM tools or even “light” BIM for specific building types like low cost residential houses, or small area building facilities.

The other one—the Geographic Information Systems (GIS)—follows the emergence in the 1960s of the 20th century territorial analysis and planning digital tools that are evolving to adapt to the new and diffuse means in which territory is appropriated by the information-based society. Together with the traditional interlacement of diverse layers of territorial information, the contemporary information practices of geo-spatialization almost allow their complete mapping on-line, dramatically reducing the gap between production and data visualization. Furthermore, the recent 3D presentations enable a friendly visualization of complex data, approaching the common citizen to urban participatory processes. The GIS experimentation field is nowadays exploring crossings with other tools of spatial analysis, such as space syntax. Other new emergent tools, such as processing, will be able to connect to GIS in a near future. Another one is ontology.

Ontologies are meta-languages for knowledge representation, and they are simultaneously a prerequisite for formal methods (thereafter out of order in this path) and a consequence of the degree of their semantic depth. Anyway, they also appear in Part I. The development of ontologies applicable to architecture and urbanism emerged from the necessity of finding common linguistic bases for the multiplicity of languages used by the numerous agents in the constructed environment. This is even more necessary nowadays, as artificial agents are more and more present. These ontologies have been used as a nuclear language in knowledge-bases of constructed environments, as well as logical assistants to design, participatory GIS, automatic acquisition of urban knowledge, and interoperability between several data processing artificial agents (CAD's, GIS, etc.). Several digital tools, such as OWL, Protégé or KLOne, with their origin in information technologies, are being used to create ontologies on the architectural domain.

Part II deals with much deeper levels of semantic organization of information, creating abstract theoretical knowledge about reality. Several very distinct formal methods are in use today, such as space syntax, processing, cellular automata and shape grammars. Although theoretical, it should be noted that they have a very strong commitment with reality, producing at the same time analysis of concrete samples and the empirical validation of the material, social and psychological theories involved.

Space syntax consist of a set of theories and methodologies used for the study and treatment of building and urban space. Spaces can be geometrically defined through more or less abstract concepts: either geographic (volumes, surfaces, axial lines, nodes), or topological (graphs or connections). These spatial elements establish simple relationships between themselves, like visibility or connectivity. It is possible to build a whole set of concepts based on these basic properties, which are usually quantifiable, such as integration, depth or controllability. These quantities represent architectural and urban realities, at a physical level (such as accessibility, connectivity), at the level of cognitive psychology (intelligibility, entropy) and of sociology (privacy, control, segregation). The space syntax have been extensively used on multiple fields of architectural analysis, especially at an urban scale, such as traffic studies, distribution of facilities or even the prediction of geo-localized demand.

Processing is a creative programming platform (IDE/Integrated Development Environment), supported by Java, that enables programming for the different areas of digital art, by structuring digital applications of visual and interactive media. Initially used for educational purposes as an open source tool, focused on teaching its own language's graphical component, Processing saw itself used by different communities, contributing for its development in fields like the performing arts, kinetic arts, real-time interactive data visualization, experimental architecture, and other fields of artistic creation and applied research. In architecture's perspective, research on generative design stands out, overcoming certain limitations associated to “traditional” methods. Here, Processing shows its biggest potential by allowing users to set specific dynamic applications that will allow the calculation of complex rules and conditions used in the creation of architectural objects.

Cellular automata is a term used to refer to a set of generative grammars where multiple agents exist with identical or differentiated rules that act concurrently in the built space. The concept of cellular automata structures itself in dynamic mathematical models with the goal of configuring processes capable of promoting self-replication. Originally, it explored a set of quadrangular elements on a grid where, following a set of rules of proximity relative to each cell (cellular automaton) along the grid, growth processes were simulated, based on the logic of complex systems. Cellular automata established itself as a process that started with small elements following simple rules (bottom-up approaches). Research has been revealing a great potential in the fields of architecture and urbanism, as it allowed the possibility of creating dynamic patterns through reciprocal interaction and conditions of neighborhood between cells. They constitute patterns from which architectural and urban formal hypotheses may appear, following mathematical approaches free from traditional deterministic constraints.

Usually they are implemented in digital tools for generic algebraic calculations or in parametric CAD applications.

In the end of Part II, a dialogue of formal theories with a completely different informal approach to architectural activities is also established. This kind of dialectics has not been neglected in this book because it serves to maintain critical spirit alive.

Part III deals with applying formal methods to the production of architectural projects. CAD is an already proven technology with its many recent developments, such as parametric processes and more semantically deep shape grammars. Although shape grammars are also analysis theories, and fit very well in Part II, the contributions in this book address mainly architectural design. Other less formal techniques, like patterns, are also addressed. Shape grammars are technologies belonging to the broader field of generative grammars, dedicated to the production of geometric shapes.

A shape grammar includes a generative algebra applied to a set of production rules. These grammars have been used in diverse areas, from technologies to the visual arts, as identifying styles of composition or as means to refine structural elements. In architecture and urbanism, this tool is used in history, theory, and critique (with examples like the definition of a grammar of Palladio's villas, or the formalization of Alberti’s production rules), as well as on automated design, based on rules defined by the architect, or according to rules or patterns identified from case studies or established practices. Research on parametric processes has been tackling the evolution of different methods and technological processes, which lies in the possibility of quick visualization, construction, and modification of concepts associated with design. These systems establish a complementary relationship with generative design, where different parameters from several different components are intrinsically connected through an algorithm, in which the variables are then verified to be adjusted to the needs of specific results.

From the initial analysis to the execution and production of final components, through the (no less important) phase of form finding, parametric processes enable singular approaches to the set of conditions of each context. These conditions are formally framed via top-down strategies, or, conversely, using informal combinations of less structuring components to promote results generated through bottom-up approaches.

In current and future architectural practice, exclusive use of formal methods is out of question. Semi-formal methods are broadly practiced and could not be ignored both in this book and in architectural real practices.

Finally, Part IV deals with the formal methods to manage and produce the real thing—the material production of buildings and constructions. Advances in computation and its use to control production machines are being applied also to architecture, allowing the automatic manufacturing of complex geometries, hardly reachable in ancient techniques and at a fraction of the cost. CAM (Computer Aided Manufacturing) and CNC (Computer Numerically Controlled) machines are enabling greater personalization, flexibility and innovation in architectural design and creative processes, providing society with new products and services.

Formal Methods Group

For several years now, a group of researchers in Escola Superior Artística do Porto (ESAP/Arts Higher School of Porto, Portugal) have been deepening the role of formal methods in architecture and urbanism. Since 2006, the first studies led to a series of conferences, courses and workshops (initially organized by David Leite Viana and Gonçalo Castro Henriques) that had the collaboration of well-known practitioners and professors like Bernard Franken and Branko Kolarevic. They focused mainly on new digital tools in parametric CAD and CAM tools. Other fields of interest in the same area were added up throughout the years, such as space syntax and shape grammars. Soon, the need to establish close links between the various areas became notorious. The new globalizing concept was baptized as *Formal Methods in Architecture and Urbanism*. Since 2011, Formal Methods Group, now integrated at Laboratório de Investigação em Arquitetura (LIA, Architectural Research Laboratory, ESAP, Portugal), is supporting a biannual meeting, counting, from the beginning, with support of José P. Duarte and the research team at Faculdade de Arquitetura da Universidade de Lisboa (FAUL/Faculty of Architecture, The University of Lisbon, Portugal). A much broader program was intended for the 3rd International Symposium Formal Methods in Architecture, giving rise to this book. This edition had the helpful collaboration in its Scientific Committee of Michael Weinstock, from Architectural Association, London (AA, UK), and Tasos Varoudis, from the Bartlett School of University College London (UCL, UK), between many others.

Formal Methods Group is continuing R&D, producing publications and exhibitions for dissemination of the field achievements, promoting courses and producing software in formal methods free for academic use.

For all the friends, cited and not cited, the editors would like to manifest their greatest thanks.

3RD SYMPOSIUM FORMAL METHODS IN ARCHITECTURE: OPENING SPEECH

FRANKLIM MORAIS

What I am about to say does not represent the opinions of the Organizing or Scientific Committees of the Symposium, nor even entirely my own.

Meetings of researchers in this domain tend to have a specialist approach, which is great for a number of things. However, we always intended to bring a broader framework to our subject. It was so in our former two symposiums and it is the same in this one. So, do not interpret what I will say as a closing directive. See it in the opposite way: the opening for some meta-discourse on the discourses of formal methods in architecture. What will seem controversial is, in fact, an appeal to disagreement.

– 1 –

What is the big advantage of formalized languages?

On TV, I saw the author of one of those street *trompe l'oeil* chalk drawings explaining his art. When asked how he painted that, he said he put a camera in the privileged point of the perspective and he drew a little, then he ran to the ocular of the camera and saw that all was well, and then he corrected the errors or drew a little more and went again to the ocular and again and again.

By Jove, by the sake of Euclid, by Giotto and Brunelleschi, by Descartes and Desargues, hasn't this person ever been told about perspective, that formal language? Didn't he suspect that he could deal with his problem in a fraction of the time and without all those gymnastics?

Now a quote from Marx's *Das Kapital* (*Book 1*, 1867):

> *A bee puts to shame many an architect in the construction of her cells. But what distinguishes the worst architect from the best of bees is this, that the architect raises his structure in imagination before he erects it in reality.*[1]

Marx was not talking about architecture alone but about our capacity to make an abstract and formal representation of the world in our minds, and to be able to anticipate mentally our future and act accordingly. Men's problems can be processed and solved first in mind, and only after are those solutions to be confronted with reality through action. With this ability, things no more happen to men. Men make things happen for their immense happiness. The use of formal methods in architecture is very old. We can read in a more than reliable written source that Solomon's Temple was constructed this way:

> *And the house, when it was in building, was built of stones, hewed and made ready: so that there was neither hammer nor axe, nor any tool of iron heard in the house when it was in building*. (*3 Kings*, 6:7)

The reasons why "*you are praised with silence in Zion"* (*placement of the construction of the Temple*) (*Psalms*, 65:1) can be diverse. Because uproar is not welcome by the Lord himself:

> *And they that hate thee have made their boasts, in the midst of thy solemnity. They have set up their ensigns for signs,*
>
> *And they knew not both in the going out and on the highest top. As with axes in a wood of trees,*
>
> *They have cut down at once the gates thereof, with axe and hatchet they have brought it down*. (*Psalms*, 73:4-6)

On the other hand, maybe because Solomon wanted a quiet place very badly, something that only a man in his situation can evaluate properly:

> *And he had seven hundred wives as queens, and three hundred concubines: and the women turned away his heart*. (*3 Kings*, 11:3)

Either way, what is certain is that this is the first written reference to project and design in architecture. It even gave birth to the first methodological prescription to architecture:

> *Prepare thy work without, and diligently till thy ground: that afterward thou mays build thy house*. (*Proverbs*, 24:27)

Please note the curious thing: this quote from my favorite book of Asian literature manifests the same idea as Marx would express a few millennia after. Although there is no more reference to the languages of the masons of Salomon's Temple, it is well known that this same precept moved to medieval times.

The one that attends a gothic cathedral finds divine the complex fitting of stones that the constructive virtuosity of the masters made perfect for the maximum stability. Moreover, those stones where all built in the yard to avoid the hammer's noise inside the church. They did not cut the stone and then go to see if it fit, and then cut another slice and go see if it fit. All the work was performed first in mind in a geometric language, the oldest of all formal methods. Only then, they produced and assembled the parts. In addition, indeed, they made a marvelous job.

– 2 –

I will continue with a quote from *Philosophy of Nature*, by Hegel (published in 1817):

> *§ 218.*
>
> *Gravity, as the essence of matter existing in itself only inner identity, transforms, since its concept is the essential externality, into the manifestation of the essence. As such, it is the totality of the determinations of reflection, but these as thrown apart from each other, so that each appears, as particular, qualified matter which, not yet determined as individuality, is a formless element. The determination of an element is the being for itself of matter as it finds its point of unity in the concept, though this does not yet have to do with the determination of a physical element, which is still real matter, a totality of its qualities existing in itself.*[2]

At first sight, nowadays and for the current reader, Hegel's text seems a bunch of silly sentences. I am old enough to be aware that, many times, when we do not understand others that is the fault of our ignorance and not of the ignorance of others. Nevertheless, although I know that Hegel's text is more than what it seems at first sight, I can be sure that that kind of speech has lost all its historical validity. It is not accepted anymore. All because of this: exactly 130 years earlier, in his book of 1687 with the same title, one of the most remarkable accomplishments of the human kind, Newton wrote about the same subject:

> *Proposition 75, theorem 35*
>
> *If to the several points of a given sphere there tend equal centripetal forces decreasing as the square of the distance from the point, I say, that another similar sphere will be attracted by it with a force inversely proportional to the square of the distance of the centres.*[3]

Alternatively, in current symbolic notation:

$$F = G\frac{m_1 m_2}{r^2}$$

The formal discourse on the philosophy of nature, now called simply science, won the battle for the current running times. Let us now move to architecture, with some excerpts from Heidegger's text *Building Dwelling Thinking*:

> *That is,* bauen, buan. bhu, beo *are our word bin in the versions:* ich bin, *I am,* du bist, *you are, the imperative form* bis, *be. What then does* ich bin *mean? The old word* bauen, *to which the bin belongs, answers:* ich bin, du bist mean*: I dwell, you dwell. The way in which you are and I am, the manner in which we humans are on the earth, is* Buan, *dwelling.*
>
> (...)
>
> *Mortals dwell in that they receive the sky as sky.*
>
> (...)
>
> *The sky is the vaulting path of the sun, the course of the changing, moon, the wandering glitter of the stars.*[4]

I stop here, because Newton enters here. Newton was the first to stop the wandering of the stars. That the stars roamed regular paths, already had our primitive ancestors realized. However, when he formalized the founding theory of physics, Newton did more than just open the way to an even more complete understanding of the rules of the universe. Jailing the stars inside their tracks was also an act of freedom for humans—yes, it is they who glitter now: going to the moon and wandering among the stars. Of course, there is also much more in Heidegger's speech beyond a bunch of meaningless phrases. Even so, I can bet that this kind of speech will meet the same fate as that of Hegel. Nevertheless, if a genius like Hegel could say what he said of gravity one hundred and thirty years after Newton, we can only suppose that the hostilities will extend in time. In architecture, if Heidegger is a second or third order Hegel, who is the Newton? I will not answer that question. I do not even know if the question can be put that way. Something I can say is that, even to arrive at Newton, there were centuries of experimentation, attempts and failures, and that there is no end—as we all know, Newton was indeed corrected, not by Hegel, but by Einstein. Newton is not an end but a moment in an endless path.

Once again, the use of formal methods in architecture is very old. The old theoretical architectural thinking has already achieved many good ideas—what we are trying to produce today is nothing other than the formalization of Alberti's *concinnitas*. In addition, every day a new contribution clears the way. Therefore, the answer to the earlier question (that I will not answer) is this: WE ARE.

Good work!

Notes

All citations from the Bible are from *Douay-Rheims Bible*, http://www.drbo.org/chapter/11006.htm.

1. Karl Marx, *Capital* (V1), Part III, Ch. 7 Section 1, https://www.marxists.org/archive/marx/works/1867-c1/ch07.htm.
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3. Isaac Newton, *The mathematical principles of natural philosophy* (1st English edition, 1729), Book 1, Section XII, proposition LXXV theorem XXXV, https://en.wikisource.org/wiki/The_Mathematical_Principles_of_Natural_Philosophy_(1729)/Book_1/Section_12#Prop75.
4. Martin Heidegger, "Building dwelling thinking," *Basic Writings* (1993), 343-64, https://drive.google.com/file/d/0BxEZ9xOtQkn2M09GS1g3RmlXaUk/edit.

– Part I –

From Information Gathering and Processing

CHAPTER ONE

BIM: CUSTOMIZING THE STANDARDS

ALEXANDROS KALLEGIAS

Introduction

BIM-affiliated software is gradually gaining popularity. Offices in different countries have developed specialized teams to work in a BIM framework in order to deal with the complexity of gathering and managing building information. The paper aims to address a key area in relation to the growing implementation of BIM in current practices. If we successfully manage to reach universal BIM guidelines and procedures for design & built projects, hence the constant implementation of building standards, what would prevent the standardization of the profession and potentially the gradual levelling of the architectural design? The question entails how a well-defined system of standardized processes for design and build projects may be practically applied in offices that are characterized by their bespoke design and workflow. This paper will discuss and evaluate the customizing of the standardized BIM approach in the current architectural practices and the way these may affect the future of the discipline.

Methodology

Architecture encompasses both the process and the output of designing physical structures. When described as the knowledge of using the tools available not only to construct one's project but also to communicate properly its particularities as well as its qualities, one should consider the ability to calculate cost, construction and building operation efficiently with these tools. Recent software developments aim for more effective information exchange and interoperability in digital format. While the term BIM has been in use since 1970s, its practical implementation took place almost two decades later and is still in the process of maturing.[1]

When referring to BIM-associated projects, it has become common practice to characterize them according to their level of compliance. Practically, this method defines the distinction and expectations among projects in terms of their collaborative nature and CAD interoperability within and outside one's practice. Lately, governments, like the one in the UK, are enacting laws as part of a long-term strategy to establish more efficient ways of working through BIM. This new way of working is being established through a gradual transition from the "old-school" drawing boards to the modern computer-aided design environments; from the analogue to the digital age of applied architecture. Specifically, in the UK, a project may be described as BIM Level 0, 1, 2 or 3. Level 0 BIM refers to a project that is effectively characterized by zero collaboration. The output and distribution of project information is made via paper or electronic prints or a combination of the two. This approach is far surpassed by most countries' industries. Level 1 BIM is the common practice in the industry where 3D CAD is used merely as a representative tool and 2D CAD drafting is being created as the main part of the project's submission. The 2D CAD here follows standards set by the respective body of authority while usually being managed by the contractor. The collaboration is kept within the discipline of each respective office, which maintains and publishes its own data. Level 2 BIM, which is currently being applied in major projects, is distinguished by its collaborative workflow among different disciplines. Design information is exchanged via a common file format. This allows each discipline to create and develop their own single or multiple models as long as they are able to share them to the agreed file format, this is usually done with an IFC file format export (Industry Foundation Classes).

Level 3 BIM is considered as the highest level: the level of complete collaboration. Currently, numerous architectural and engineering practices worldwide are heavily investing in the training of their employees in order to expand their skills on the use of BIM design software.

In the race of becoming excellent in BIM software, it is crucial to preserve one's ability of communicating the design intent beyond the technical obstacles that one had to overcome. Therefore, all major and detailed aspects of Level 2 BIM projects require a commonly agreed execution plan. It is imperative to establish clear and complete protocols and guidelines before one embarks on implementing BIM on architectural projects. Compared to the enduring battle between computer-aided design and hand drafting, the argument for BIM implementation has to surmount an even greater series of deep-rooted and often archaic work methods and dispositions. This involves educating equally the office colleagues, the different consultants and clients.

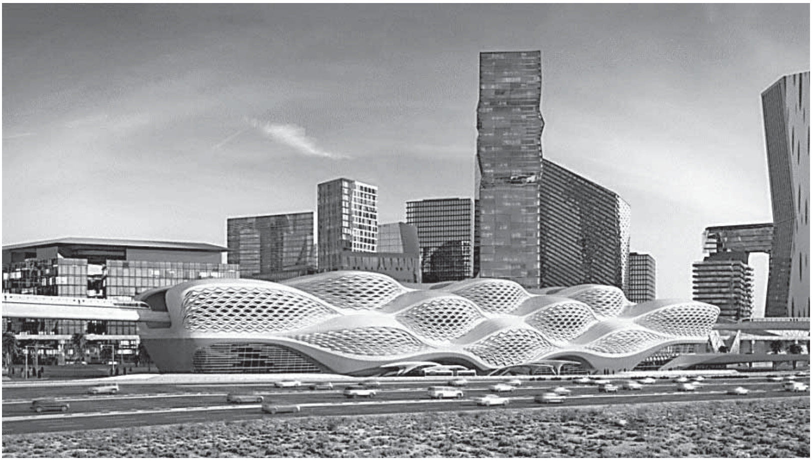

Figure 01.1
King Abdullah Financial District Metro Station.
(Image courtesy of Zaha Hadid Architects at www.zaha-hadid.com)

Application

It has been over a decade in countries like Norway, Finland and the United States since BIM has been adopted via legislation by the government as the path for major projects delivery.[2] This initiative has extended in the past years in more countries across Europe and Asia such as the UK, Denmark, the Netherlands, Hong Kong, South Korea and Singapore. These efforts have need of a thoroughly examined execution plan of adoption. The necessity of such a plan is clear; however, the task of bringing clients, consultants and colleagues in agreement requires a certain level of communication skills beyond the technical knowledge.

Lack of communication and miscommunications can often cause various project delays and difficulties. Therefore, it is necessary that all BIM standards are well implemented and established at the beginning of every project. In this regard, it is equally necessary to provide all possible information to the client to create a healthy working relationship. This also helps to establish a clear understanding of the different stages of the project; it can provide insight for future project parameters and requirements as well as establish and manage expectations. This is a typical case for many international architectural offices such as Zaha Hadid Architects.

Figure 01.2
King Abdullah Financial District Metro Station.
(Image courtesy of Zaha Hadid Architects at www.zaha-hadid.com)

In an engineering BIM standard manual, it is imperative to clarify many different aspects of setting up and operating a BIM model. Initially, the software-modelling guide is set. The software-modelling guide refers to the standards that the project teams need to follow in terms of the model content, its setup and its method of modification. The model content is defined in terms of the level of detail required for each project stage to the modelling of elements in order to carry the necessary info for the metadata applications. Elements are tagged with a unique ID in order to be tracked throughout the making of the project. Detail and enhancement techniques are often used to improve speed and reduce the model's complexity. In addition, the level of development is set for the model planning of each stage. To maintain the model's data integrity, changes are carefully monitored and regular auditing takes place to ensure good model health. Equally important is the model organization. Here, the guidelines define the different types of BIM models to be created and how they should be used in accordance with each other during the project. The need for discipline-distinct BIM models (Architecture BIM, Façade BIM, MEP BIM, etc.) has the benefit of keeping a well-organized sub-categorization of various discipline and type models in addition to keeping a manageable file-size. All naming conventions are to be set once and should always follow the primary naming system to ensure proper coordination for drawing production purposes but also for coordination with other data such as geo-referencing and locating other facilities.

In BIM Level 2 projects, the publishing part can also be distinguished as one of the most vital parts. Typically, the different disciplines have access to a specific platform shared across the internet where they can safely share information in the form of models or other documents. By default, this common platform provides the options for the creation, modification, management and distribution of work-in-progress items. The work-sharing can take place in real-time among the project teams, both locally and globally, while the files created are kept in the system's database at all times. This way, the control of access and modification is secured through user permissions and the status of the various documents. While this approach becomes ever more popular and architectural offices become ever more adept in the usage of BIM, the building industry is following on a much different rhythm.

BIM offers accuracy and timesaving, however its ability to swiftly provide quantity take-offs and cost estimates is not absorbed in its full potential by the industry. Specifically, there is room for improvement in the handover stage where a potential contractor—while able to deliver the required parts—may face technical and conceptual difficulties in receiving project information in formats other than printed paper or segmented digital documents.

Different classification systems from different places in the world result in having to add an extra step in order to correlate helpful information of different naming conventions. Thus, with regard to off-site manufacturing, it can be argued that utilizing BIM has not been achieved to the maximum yet as most contractors are still struggling to merely use non-proprietary 3D models. Hence, during the handover stage there may be an incorporation of Templates & Specifications manuals to the BIM practice. Specifically, in an effort to overcome any communication gap due to technical discords between the architect and the contractor, the most straightforward option would be for architects to provide printed guideline manuals to their respective contractors.

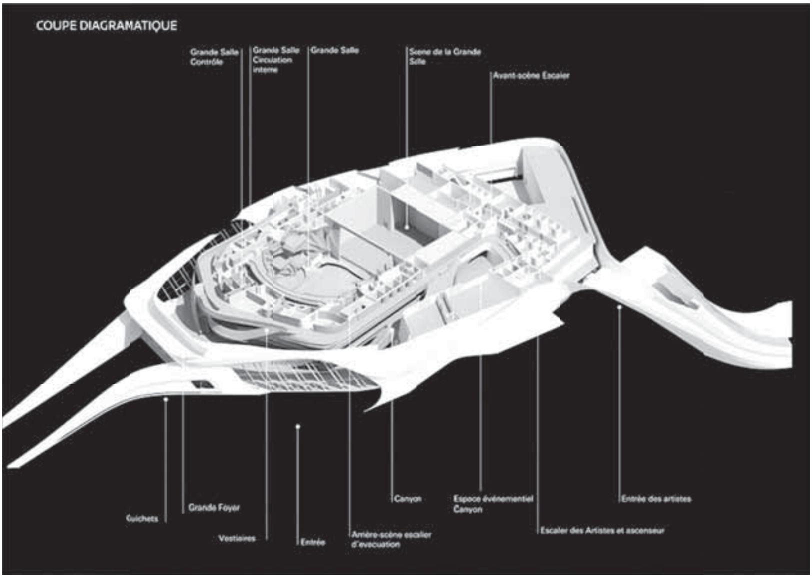

Figure 01.3
Grand Théatre de Rabat.
(Image courtesy of Zaha Hadid Architects at www.zaha-hadid.com)

Nevertheless, aside from any printed manual, the ability to store, manage and share project-related data in digital format and under established protocols enables the visual simulation of events on a time-line populated by a 3D model. This can then be associated with cost estimates and eventually be connected to the entire life span of the building. Also known as 6D BIM, it is usually referred to as the intelligent linking of the "As-Built" BIM file with relevant building data like product codes, material specifications, manufacturer info and contact details, etc. The existence of such an architectural output requires proper, well-organized, and thought-through project management and supervision. It requires that senior architects with experience are involved to efficiently anticipate and set the conditions of all the building aspects—from concept to construction.

Discussion

The current tendency in companies is the focus on improving the various collaborative processes that characterize BIM Level 2 projects. They do so by improving the workflow in segments.

In the event of a problem, this is usually being dealt with “locally” and its solution often becomes ephemeral. Rarely, there is a strategy to provide with a working solution that may encompass the entire system and not its parts individually. The adoption of BIM Level 2 standards shows indeed benefits for the architectural discipline in terms of a project’s design coordination. However, during the construction procedure the clarity in the exchange of project information is not always maintained.

While having separate disciplines exchanging their data among each other through export/import of their models, the risk of errors in the versioning, the data storage, network control and more carries a significant danger for the project’s successful completion. Since there is no seamless transition from the design stage to the fabrication stage, the work may result in drifting away from the initial design intent and architects entangled in a vicious cycle of detail information requests. Even if the implementation of Level 3 BIM standards is not yet fully established, looking further ahead such an initiative would bring considerable advantages in reducing ambiguity of information across all project stages, minimizing data exchange errors and communication discrepancies as well as unproductive work.

BIM Level 3 aims for fully synchronized workflow with direct feedback capabilities. Working with these standards, there is one integrated model open to all the relevant collaborators on the projects, architects, civil engineers, MEP engineers, façade consultants and landscape consultants as well as the client’s team. If that is made possible, then additional steps can be made to further advance a project’s level of collaboration.

Additional information about the operations of the building can actually be incorporated; it can be considered as part of the concept stage. Therefore, the primary steps of a project may already be informed by certain crucial attributes like the type, origin and amount of materials needed as well as the intended use and its weathering properties. At this point, the fundamental characteristics of architecture as an interdisciplinary field become evident and important for the successful delivery of a project in practical consideration of its life cycle.

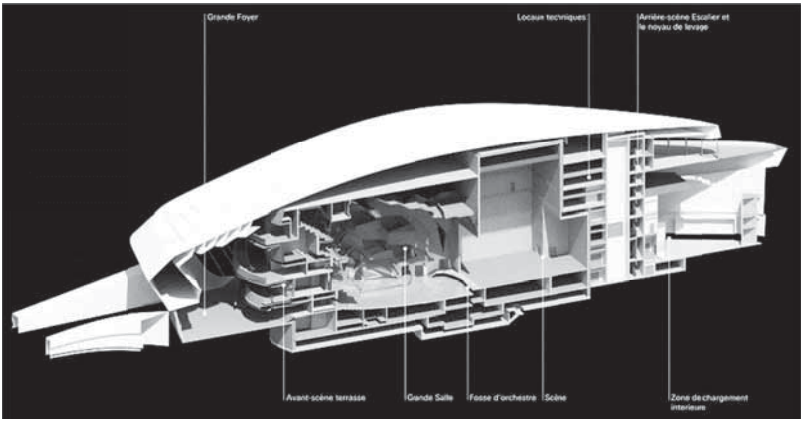

Figure 01.4
Grand Théatre de Rabat.
(Image courtesy of Zaha Hadid Architects at www.zaha-hadid.com)

At Level 3 BIM, the concept and delivery coordination that from early on actively involves the architects, consultants as well as the potential contractors, may benefit from creating less redundant work, shorter delivery time and a much healthier profit margin. The concept, usually referred to as 4D BIM, allows the architect to visualize the different phasing and spot certain defects before the start of construction. Moreover, 5D BIM connects the time phasing with specific cost estimates in market and eventually one can argue for the 6D BIM where the actual occupancy and facilities management is included, thus providing a truly integrated, open BIM approach. The initiative to work with BIM standards at 3D to 6D levels in the applied field of architecture carries the potential of shifting, once more, the way architects think and deliver projects. It should be noted that it is a different medium than printing or 3D modelling. It presupposes that the architect is fully capable to organize and foresee many, if not all, of the factors that affect the workflow and successful delivery of the project at the preliminary level of the design. In other words, there is an opportunity for applied architecture to revisit some of its previous procedures and establish steps that enable novelty in the design processes. When successfully implemented, BIM contributes in the collaborative character of constructing a physical structure with benefits via effective clash detection procedures, design coordination of different scale building parts, and reduced health and safety risks.

Figure 01.5
Grand Théatre de Rabat.
(Image courtesy of Zaha Hadid Architects at www.zaha-hadid.com)

Automation in construction may have its advantages in terms of time and cost, nevertheless the price may come in the form of lack of planning and style. Multi-disciplinary private construction companies will be the first to welcome and expand the use of BIM in architecture. In their likely plan to optimize cost and time, the design concept stage will eventually be automated as well. This plausible scenario requires a counter weight; it is in the hands of bespoke architects to balance and resist any case of further automating architecture. It is architects with sophisticated design sensitivity who not only make an impact to the architectural contemporary style but who also affect the construction industry. Almost acting as two opposites with a portion of the opposite field in each part automated, "off-the-shelf" construction and bespoke, "tailor-made" architecture need to be equally developed in order to have constant equilibrium both in aesthetics and performances. With this in mind, governments around the world invest in BIM technologies; they should however be investing equally to enterprises, institutes, offices and individuals who refine their architecture while being unique and exemplary.

Notes

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CHAPTER TWO

BIM ONTOLOGIES

ANTÓN CASTRO, DAVID LEITE VIANA
AND JORGE VIEIRA VAZ

Introduction

Computers are changing the language and the architecture display; they are acting as a database to handle more information and to design more quickly and accurately. Any process becomes quantifiable with a language based on mathematics. According to Coloma Picô, the use of BIM tools (Building Information Modelling) for the creation and implementation of design project processes stands out in the use of computers.[1] BIM, through its application software, becomes a new way of understanding Architecture. It is a common tool of formal methods to communicate architectural knowledge. Collaboration ontology allows BIM to characterize and share a working model of managing information as a knowledge process. The search for the relationship between ontologies creates a language of understanding of the process that it is being developed to contribute to knowledge. Ontologies are backing the development of a common template to create a shared understanding. This generates a functional system: objects container, class organizer, interface software, and information manager. Ontologies dynamically act as an object organizer of a catalogue of patterns. They facilitate the use and development of software systems for managing knowledge of a data model that uses advanced resources for the implementation of a common vocabulary.[2] Ontologies can guide the development of new information systems and thus they help analysts and designers who choose the appropriate processes, algorithms, rules, and software components, depending on their needs. The use of ontologies in information systems became popular in fields such as web technologies, database integration, multidisciplinary systems, artificial intelligence, and natural language processing.[3]

Ontologies & BIM

There are many types of ontologies to design computable objects: for retrieving data, as a model represented in OWL (Ontological Web Language); for linking data and as a definition of interoperability XML (Extensible Markup Language); and for databases. Ontologies can be classified by the expression and formality of languages used in data communication or by the objects described by the ontology. Ontologies applied to BIM are part of the contribution to knowledge acquisition and to the communication among BIM applications' users. Provision of knowledge is made throughout semi-structured and informal schemes that include content of specific concepts. Their relations and attributes are the base for the knowledge and they structure such knowledge to communicate necessary concepts for the architectures to be able to represent geometries and to work collaboratively with a computational language common for all users.[4] Content structuring of the ontology can be represented in different ways using conceptual schemes with different graphics, so these graphics endure and contribute to the knowledge of communicating the use of BIM technology to the users interested in changing their work methodology.[5]

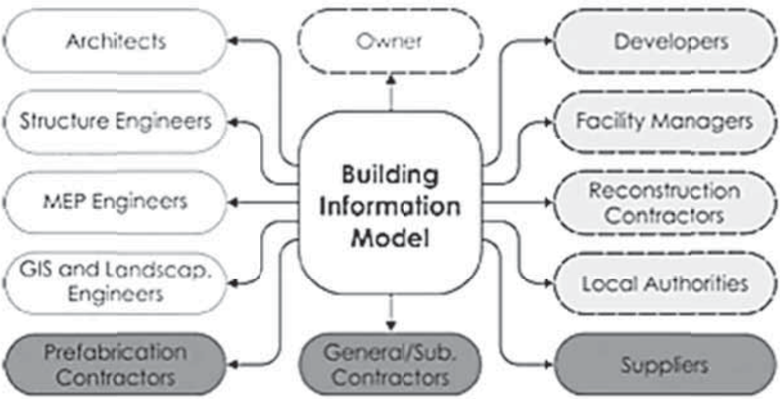

Figure 02.1
Conceptual diagram of BIM specialties (in Kalinichuk, 2015, p.29).

The concept map of BIM specialties shows the interactions existing among BIM with the AEC specialties, the relation with owners and designers, and the stages of development of the architectural project.[6] The conceptual scheme organized at a hierarchical level contributes to the knowledge to guide the users involved in the project along the different stages of the design and the relations with other specialties, taking into account BIM technology capacities to integrate and manage information in digital modelling. According to Noy & McGuinness,[7] the development of ontologies is necessary: *i)* to share common understanding of information structure among people or software agents; *ii)* to allow the reuse of specific domain knowledge, such as BIM; *iii)* to make explicit assumptions about concepts treated by software applications; *iv)* to separate BIM knowledge from operational software knowledge; *v)* and, finally, to analyze domain knowledge. BIM ontologies are used as an abstract representation to visualize concepts and relations, and to analyze the domain knowledge. BIM includes data, information and semantic knowledge transactions. It is based on the representation of experts in the field who structure their knowledge through qualitative mental models. These models help the users to orientate themselves in the BIM technology through the reasoning of concepts needed to make the architectural design and understand the constituent parts of BIM that contribute to knowledge and its communications. Concepts for the analysis were based on the literature revision of authors, such as Gruber, Noy & McGuinness, Trento, Coloma Picó, and Succar.[8]

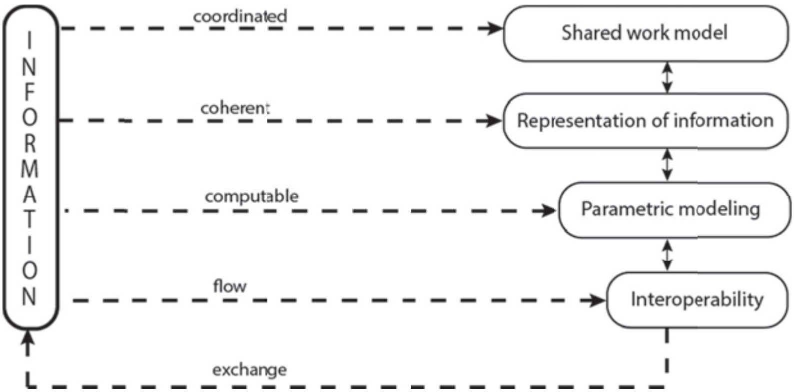

Figure 02.2
Conceptual diagram of ontological relations within BIM processes
(in Coloma Picó, 2011, p. 55).

To develop a project in BIM ontology, it is necessary to understand the capacities of the technology involved in the process, as well as their ontological relations to manage the information fluently. The capacities that identify BIM technology are as follows:

a) Shared work model: In BIM technology, there are many specialties such as Architecture, Engineering, and Building; which share a common virtual workspace to communicate among themselves and to move towards achieving one goal of design.

    - By using the same working model with a common language, communication capacity becomes more dynamic, allowing cohesion of the information, constant updating, and linking different specialties, thanks to the shared design.

b) Representation of the information: In BIM technology, information can be represented in different ways, such as 2D designs, 3D designs, and data tables, providing cohesion to the information.

    - Having different visualizations to compare the design with means to allow the design to be compared more easily—it improves the veracity of the information integrated in the object.

        - Every specialty can choose how to represent the content or how to visualize it to better understand and improve the content; all the parts of the project can be checked and verified by the users because they are on the same platform with a common language.

            - The representation of the information in a dynamic and automatized way allows the work group to express in a coordinated and coherent way, and to reach consensus among the parts.

c) Parametric modelling: It is necessary that BIM technology integrates parameters in the model for the information to be computable.

    - Parameters are characteristics of the object that relate it with other existing objects; without the parametric capacity of BIM applications, the information flow would be neither dynamic nor fluent; it would be static without regularly updated data.

- The parametric capacity of BIM is used for integrating content to manage knowledge and for communicating it in the most efficient manner, which is defined by properties, parameters, and attributes.
    - All this information content is part of a database managed by all the users that is available to be consulted throughout the life cycle of the building.

d) Interoperability: To manage the database among several users and applications, it is necessary to have formats of common language to favor the coherence and for the information to be universally understood. Language formats are normalized through the ISO-STEP standard that supervises the evolution and adaptation of data exchange.

- Some exchange formats are IFC, CIS/2, ISO 15926, all of them use the EXPRESS language; with the development of these formats, storing information in a file with common language to communicate among different BIM applications, data exchange facilitates the workflow.

Without parametric capability within BIM applications, communication process through modelling would not be possible. It constitutes the link that helps the building specialties to integrate data in a common model with the same perceptible language for all the users who design an object. With data interpretation of applications, different representations of information help to understand the designed object and facilitate the communication among users through visualization of 2D/3D model and generated data.

BIM applications are a virtual space with a common language to design construction objects where specialties that communicate through data exchange participate about concrete topics, such as slabs, walls or roofs. Methodology generated by shared work among specialties makes the knowledge of BIM ontologies necessary to ensure the flow and veracity of information in the stages of the project.

BIM ontology is an explicit specification of the parameterization of an object and the integration process of information in the design, based on concepts shared by all the users of BIM applications for communication and design. Ontology arises from the need to share information in a coordinated way among all the specialties of construction and to represent a BIM model with a same common language to the users.

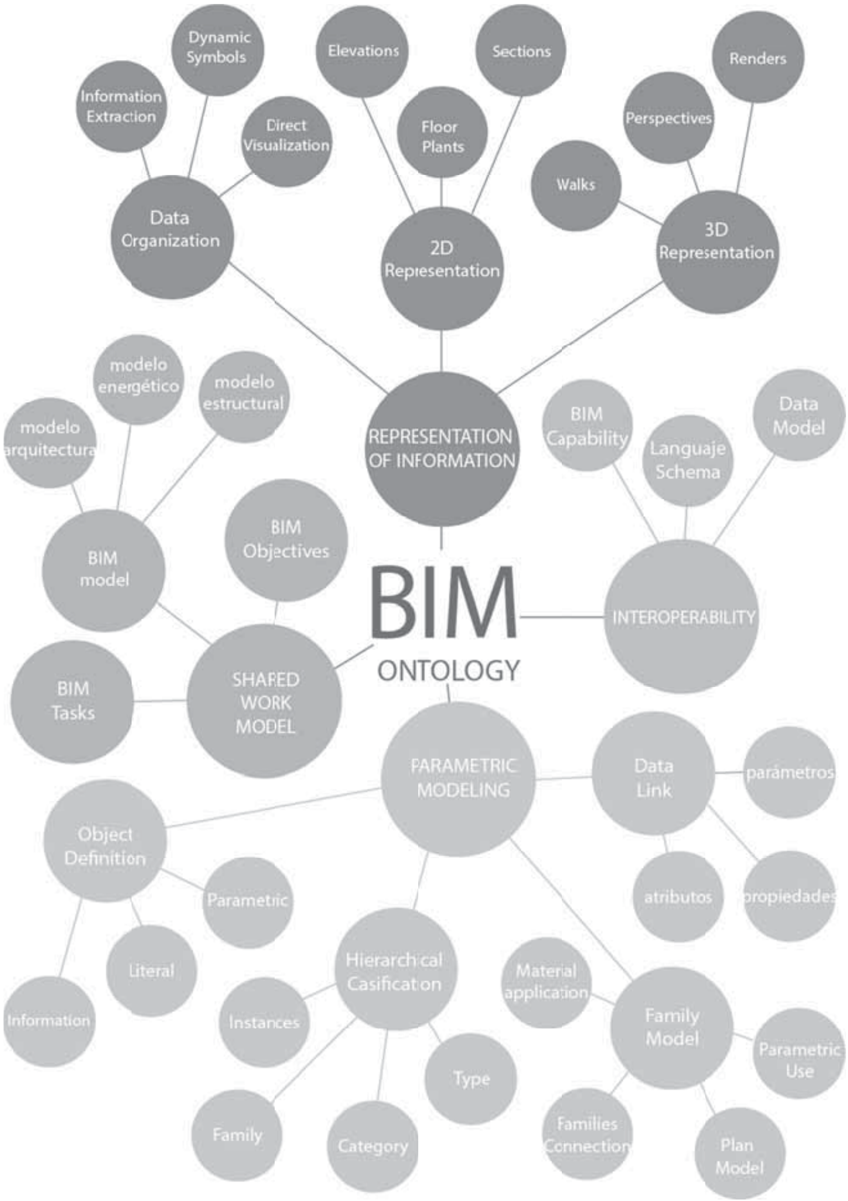

Figure 02.3
The sort of coordinated relations to be set within a BIM ontology.

The next section of this chapter will analyze concepts, relations and attributes of parametric modelling necessary to integrate information in the designed object and represent it in different views for a better understanding, analysis and cohesion of the different construction specialties through BIM applications. Parametric modelling is supportive in managing the database of the designed object and, thus, in extracting information to justify the project brought to reality.

One of the parametric modelling capacities is the dynamic character of the applications to make modifications throughout the project's life cycle. It facilitates the process of the project since modifications are reflected in all the designed pieces, both drawings and data tables, generating a constant update of the database managed by the users who use ontological processes to appropriately integrate information.

Parametric Modelling

The knowledge of BIM ontology facilitates the user to understand the work methodology of the rest of users and their own, achieving a better adaptation to the integration flow of the information in the work model. The hierarchical scheme of ontological concepts describes the parametric modelling of BIM information.

Concepts covered in this section help to understand integrated modelling of information in a parametric object for its adequate management and communication. Parametric design means that an object can have information for the analysis and use of such object, being possible to automatically make changes in the model, since it is integrated: literal, parametric or informational. The object's information content is important, since the quality of the object's design can be detailed for its adequate communication.

Parametric objects in BIM are organized according to their category, as door or window, based on the family that they represent and then, within the families, into types and instances, such as a door of a single-leaf door or a window of a hinged window.

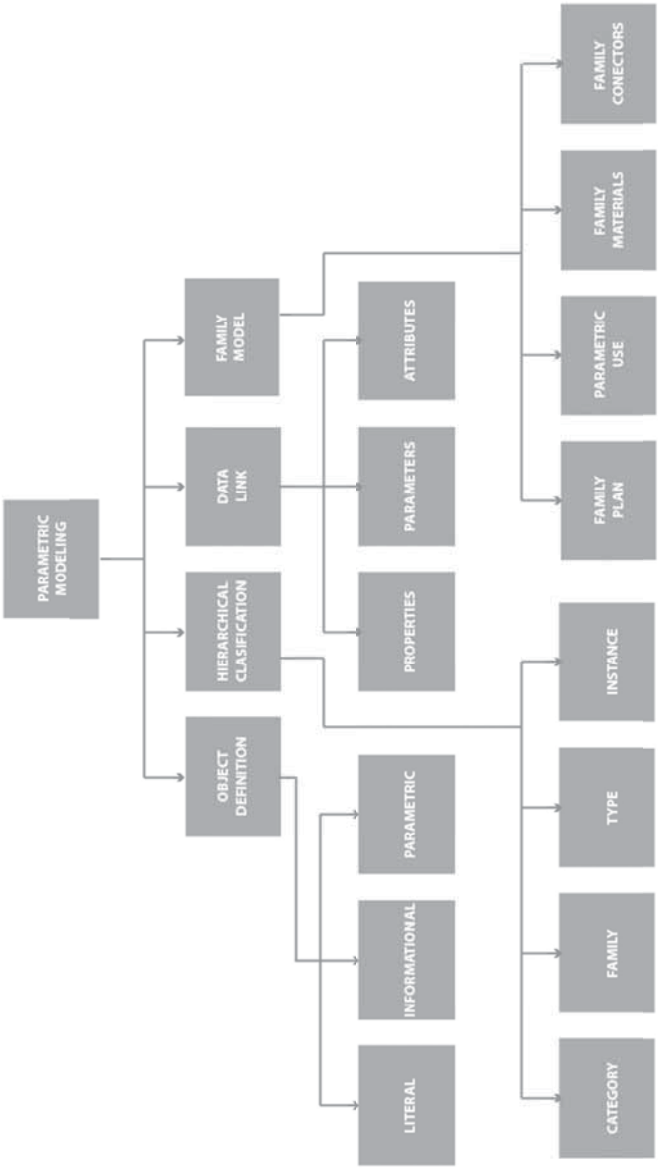

Figure 02.4
Parametric modelling ontology.

The classification that BIM uses for objects defines the object's information from the general to the particular, articulating its content and nomenclature in the stages of the project. Families are related in the object's modelling thanks to their relations in the content that integrates them. Data links between classes are defined by properties, parameters and attributes—needed to create or modify the existing relations among objects or common characteristics for their interpretation.

By realizing the importance of the object's information content to communicate it or formalize a link with the rest of objects, qualities that a family should have for its correct representation have been deepened. To accurately represent one family, it is necessary to consider the family model that is being created, the accuracy of the management of the design, the units with which the design is formalized, and the simple and adequate nomenclature in the description of the object that is being modelled. Thanks to the information in the BIM objects, truthful and coherent communication takes place that is adequate to the design that will be formalized.

Representation of the Information

The hierarchical scheme of ontological concepts describes the representation of the information in BIM. Concepts covered in this section of the chapter are general ideas about the integration of the information in the work model and how the pieces that are needed to develop a project are represented. Due to its dynamic capacity of information management and updating, BIM applications with a parametric base establish relations among 2D, 3D, the organization of the information and the design criteria for the work model to be truthful and current.

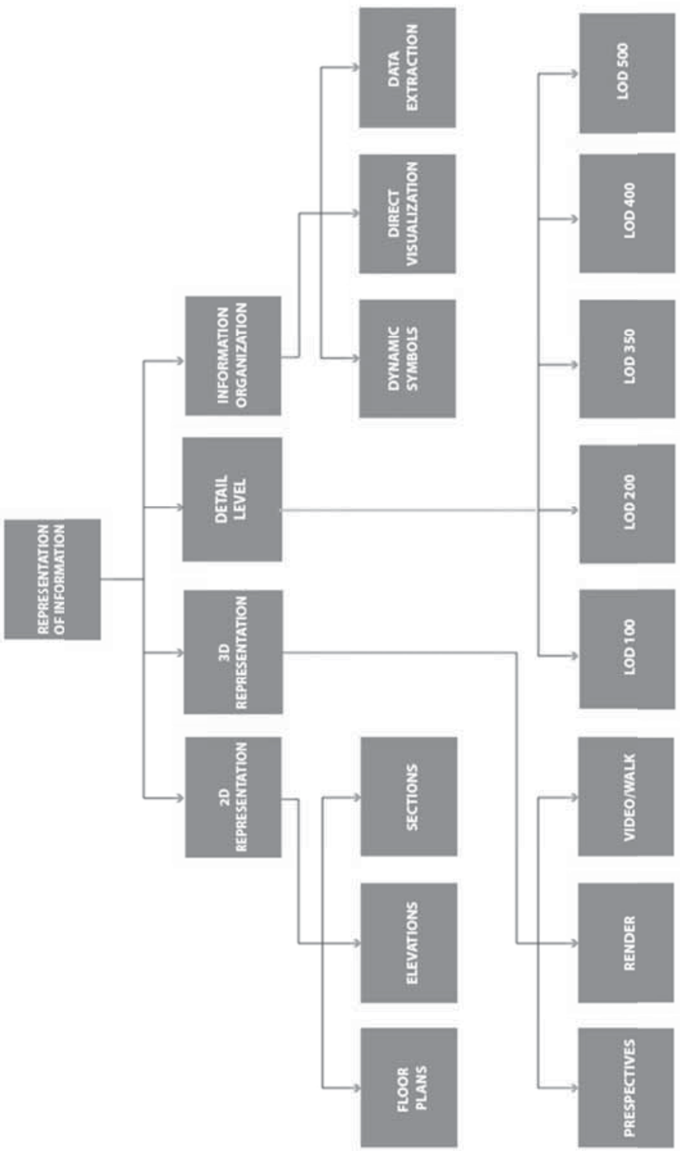

Figure 02.5
Representation of the information ontology.

With the introduction of data in a 2D simulation, the same representation in 3D is automatically generated, since the designed elements also contain special information associated to their three-dimensional representation. Applicable elevations and sections are also generated maintaining cohesion with the rest of the designs. Coordination in the work space, and the information, provides the user with a better communication and analysis of the architectural design, being able to choose several representations for the correct understanding and magnitude of the design. For the entire process to be coherent and coordinated, 2D and 3D designs are subject to criteria of the information organization and design for the correct execution and representation.

But on the other hand, formalization of dynamic symbols and the execution of one level of design facilitate the understanding and concretization of the design among several users that act in a coordinated way when designing with the same expression language.

Connection among different designs of the project creates communication in the application, contextualized by the interactivity of the program and the tracking process to integrate data in the model.

Shared Work Model

The hierarchical scheme of ontological concepts relates capabilities of the work modelling shared among specialties. Concepts covered in this section of the chapter are to define the relations of objectives and tasks that users have in common and that integrate information to contribute to the database of the model.

Once BIM objectives towards the project are set, tasks for the execution of the model—from the design up until it has been built—can be specified. When an architectural project in BIM is designed, the architect is in charge of managing the database, collaborating with specialties, such as structures or energy, to complete and verify the information included in the model.

The architectural information must be sent to other specialties so that their part of the work can be analyzed and designed in a coordinated way. When the database is coordinated by applications with computational language, integration of information is up-to-date, and it is assured that it has been introduced with the established rigor by the design of the application. All the users need to reach an agreement in the criteria of representation and detail to properly design all the pieces that make up the object.

One of the important factors of BIM is data communication to manage information. Thanks to this quality, its magnitude, through the conceptual modelling of mass and the data comparison such as area, volume or levels of the object, can be perceived right from the very early stages of the project. This allows a previous study to be much more detailed and quantifiable, and to be communicated much better among specialties.

Data extraction is made through planning tables and designs, which is the way to communicate among specialties. Several users can manage the same work model and collaborate using architectural expression in BIM applications as their language.

BIM Interoperability

The hierarchical scheme of ontological concepts describes the exchange of BIM information. The interpreted concepts in this chapter are general ideas for the cohesion of the formats and information exchange languages that exist in different stages of BIM. To link the specialties associated to architecture and ensure a truthful sharing of semantic data of the object the EXPRESS computational language, used by BIM tools such as Revit, is used.

Interoperability is a key point to share parametric information in BIM, allowing communication within design specifications and the main file, setting the standard of the content of the common information for its exchange. Interoperability is the ability of two or more systems to exchange information and use information exchanged to define a space model or a context. The models generated by BIM are broad and with great capacity for all kinds of content, structuring a joint database to manage and coordinate projects.

Discussion

This chapter tries to clarify the constraints that characterize BIM ontologies through the analysis of domain concepts, relations, the attributes those concepts have and their contribution to knowledge of these concepts' hierarchical schemes, which represent contribution to knowledge and its diffusion. To establish an analysis strategy, the ontological concept of the philosopher Aristotle and metaphysics is used to identify existing ontologies in other specialties that will provide us with a theoretical frame of intervention to represent the reality around us.

The desire to represent reality does not only cover Philosophy, but it is also common to Architecture and Urbanism. Vitruvius, in his book *De architectura,* collects the ontologies of the Greco-Latin architecture for its subsequent interpretation in the search of architectural beauty. With the ontologies' recovery in the computational field,[9] concepts for the management of information with computers for a better management of databases and analytic capability and semantic OWL start to be implemented.

Urbanism uses software applications to manage wide databases and, thus, to establish an action hierarchy based on the data collected during the analysis, and it uses ontologies as a means to communicate and relate users and data.[10] Once the ontologies represented in Architecture, Philosophy, and Urbanism related to the management of information and design have been identified, examples to detect slight ontologies in BIM will be applied, specifying action fields like representation, shared modelling, interoperability, and parameterization. Those are created with a common language to all users—a language used to communicate information. The future of information management lies in the parametric families that form objects included in the information and that are important for the communication. BIM applications integrate the semantic modelling of the object through data parameterization to be managed with a software application that has a computational language.[11] Concerning relating information, it is necessary to follow format criteria so—when the information is integrated in a virtual model—this does not report assimilation errors or does not properly interact with the rest of the designed objects.

It is necessary to emphasize the formalization of the parametric components, since it means a contribution to knowledge. Currently, studies are being developed to improve semantic definition of data in the families, since their misuse can lead to errors in the application system. Families are objects with semantic content that are used to analyze and verify the work model for a better integration of the designed elements. By introducing BIM applications, new limits for the creation of semantic objects related to their environment are set. As technologies progress, the semantic quantity of data is more detailed and differentiating between clear and general concepts for their use and understanding is needed. Capabilities of BIM technologies to describe a building from the parametric geometry are revolutionizing construction technology, since there are applications that allow collaborative modelling and integrating all disciplines to develop objects of a digital origin. How Architecture is reflected in reality is one of the main goals of these objects.

In the following figure (02.6. BIM ontology), which discloses the interrelation of the referred concepts throughout the different sections of this chapter, one can understand how the semantic data is integrated in several objects and how information is treated by the BIM application, which integrates data for further analysis.

Concepts like families' creation have to be logical to all users to be appropriately interpreted in the most efficient way so that the model can be verified. BIM is forcing new ways of design thinking and it is promoting a more integrated and systemic approach to design processes, articulating Design, Building, and Management.

The chapter reveals (in a summarized framework) the potential of ontologies' definition in BIM's workflow, context, and operationalization, concerning subjects like parametric modelling, information's representation, work model, and interoperability between BIM platforms—in order to suppress one of today's constrains when using this method: to achieve a systematic process to approach design thinking as an integrated, multiscale, and cross-sharing set of procedures and protocols wildly recognizable and useful towards overall building sustainability.

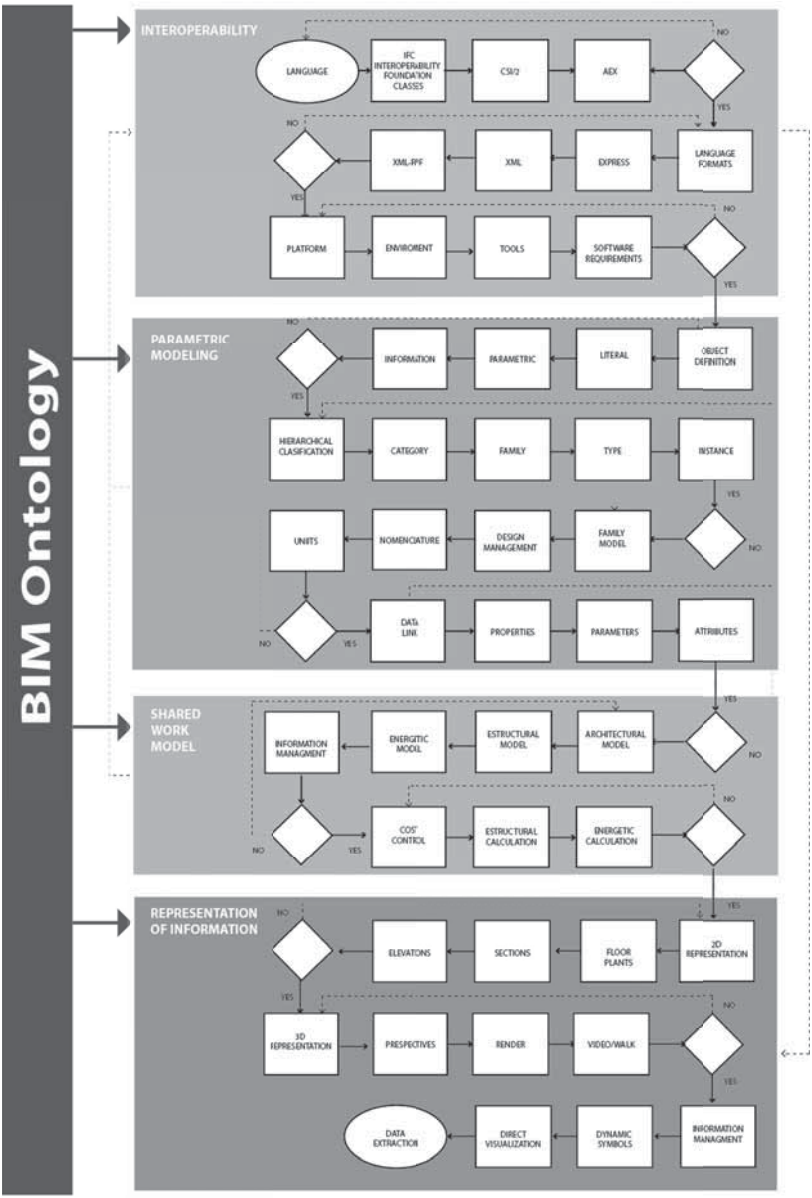

Figure 02.6
BIM ontology.

Notes

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Chapter Three

Menarch: Ontologies in Architecture— A Study on Architecture Social Function

Frederico Silveira

Introduction

Before entering the subject of this chapter, one should first share some thoughts on the meaning of architecture—conceptually defined by the sublime mixture of science and art, with the purpose to study, to interpret, and to portray (to model) the human condition in its environment. It can be said that architecture was born from the need of humans to find shelter from the adversities of the environment and has since evolved to work with every scale of daily life. Adding to the creation of the first structure, men started to communicate through architecture, adding an aesthetic function to their created ambience. With the first shelters came the first settlements; therefore, there is no architecture without the human individual and a community. In the Athens Charter,[1] the quote "from spoon to the city"—*Dal Cucchiaio alla città*, by Rogers (recorded in 1952)—explains the approach of an architect designing a spoon, a chair, a closet and, the same day, a skyscraper. The formal product of architecture is the spatial awareness and inherent functionality that conscientiously influences users, contrasting the technical formality statement that engineering strives for. It has understood the effort that architecture makes to adapt to the place and its people, generating atmospheres through the manipulation of elements like shape, texture, or colour while engineering follows a more objective path, perceiving users through their assured physical needs. It is possible to accurately say that architecture is all about a structure of communication between the individual, society, and the built environment.

Early Urban Concepts

Genius Loci and the Phenomenological Act

The Roman notion of *Genius Loci* believes that every being has a genius, a "spirit" that protects people and places, determining their character.

Different places have different identities; this is what gives the sense of the place and it is the premise for architectural design. Norberg-Schulz commonly uses *Genius Loci* to define the communication between place, identity, and architecture.[2] Both constructed and natural characteristics define the "spirit" of the place—features like light, materials, morphology, social customs, interaction, architecture, and the phenomenology of the environment. These characteristics are studied in the exercise of architecture, promoting the communication between community and place. If this is not the case, the space probably becomes inhabitable and there is a rejection of the place and therefore a lack of communication. When the interpretation of the place is correct, and the use of architecture is positive, places become the support of human activities and the promoters of men's communication. For every activity, there is a specific set of features to be added in a place to stimulate different rhythms. These rhythms are marked by different factors like the gender of human activity, the architectural typology, and time. As time seems to be "running faster," the evolution of the discipline of architecture is also coming a long way since Rossi's reference to *Genius Loci*,[3] the "spirit" of the place and its relationship with architecture.

Post-modernists started by understanding the importance that is to perceive experience as a timeless language, changing the theory of architectural history and its legacy. The plan was never formalized as the theory was often more dependent on contradicting modernism, setting in place an anti-modernism thesis rather than a reinforced objective materialization of the premises, leading to contradicting theories on architectural practice. It is understood that the downfall of post-modernism was the focus on aesthetics in favor of a social consciousness on urban planning. This does not mean that all postmodernist attempts were a mistake—some creative works have successfully brought an identity to the place—although they were more focused on aesthetics and decorative elements while alienating men from his habitat. There are no places without man, there is no architecture without the consideration of the *Genius Loci* and postmodernism, probably unintentionally, has contradicted these guidelines by censuring the same attitude in modernism.

Frampton describes the post-modern attitude as a scheme that the architects use to feed the viewers with ostentatious images.[4] This reduces the architectural practice to a builder/architect scheme where the builder choses the main elements of the project while the architect just makes it more appealing by throwing an attractive mask over the skeleton. The focus should therefore be a phenomenological attitude, outside of the central communication centers and more sensitive to an innovative place identity creation in its true form.[5] Distancing the place away from the stardom architecture and capitalistic world would open new possibilities in place making. The result of this peripheral spot in the urban tissue would start with an instigation of people reclaiming their space and cultivating their cultural identity contradicting the consumerist civilization. Territorial separation is imperative to the formation of these niches, not in a physical form but promoting identity separation between different niches. Urban planning was once defined by boundaries and individuals related to a defined space that gradually disappeared, encouraging the formation of mega urban space and mass culture. Envisioning the creation of these urban borders, Frampton contemplates the reoccurrence of the traditional morphology with the deep-rooted block units and street identity.[6] Understanding space composed by different identity layers that appear in different shapes and sizes, architects need to encourage the creation of translated places that are composed by different atmospheres, exhibiting the culture and customs of their users. Several architects have set examples and investigated the phenomenological aspect of place as a unit with a variable size.

In *The Good Life: A Guided Visit To The Houses Of Modernity*,[7] Abalos studies the ways of understanding and creating different houses, diverging in planning and living. These houses are defined by boundaries and shapes, revealing different interpretations of the “spirit” of the place studied through a phenomenological point of view. The workflow surrounding these houses’ typology study is not appropriated by temporal concepts but still contemplates the relationship between users and their space habitat. Abalos explores the world of housing space through the eyes of an individual, created by his own experience and aware of the world and life, accepting that the phenomenological aspect of space is not related with man’s definition of time.[8] In a way, the user defines their space through accident, where the happening is the definition of the way the space is lived. In *Modern Architecture*,[9] Frampton shows examples of phenomenological happenings like Mario Botta’s *Morbio Inferiore* School in Switzerland, a space providing the compensation for an un-existing cultural space and urban community habitat.

Frampton also exposes the Tadao Ando's Festival Center in Okinawa prefecture (Japan) for creating a new way of reading an urban shopping center and, on the other hand, Getty Center (by Richard Meier) as a place that acts as a cultural center for the district.[10] Getty Center is described as an urban form that is composed by the traditional avenue, block and arcade, creating different niches, with a phenomenological approach and contradicting the consumerist globalization that tends to regulate urban planning. Frampton defends a method of architectural practice that is an extension of the drawing action.[11] While in drawing there is a connection between eye, brain, and hand, Frampton proposes the process of place planning to be constituted by hand drawing, digital processes, and physical modelling. It is suggested that today planning is vulnerable to digital representations and manipulation, while architects forget the palpable act on the planning process. Frampton is not excluding virtual and digital act in architectural planning,[12] however he criticizes the way architects uses these tools, trying to mislead the user by creating architectural frames that don't respond to the phenomenological aspect of place, while some architectural problems such as production value, static and heavily complex, stay unresolved. There is a need for material place definition in a phenomenological approach, as architecture's discipline is to study the art of building by understanding the singularity and interaction between different people and different places. By not forgetting the visual, there is a necessity to recreate materiality and allow users to become intimate and familiar with their surrounding space.

Heritage and Manifestos as Vehicles for Communication

Nowadays one can observe places becoming increasingly ephemeral, everything evolves faster, and this does not mean that there is no heritage in the making. Architecture phenomenology, as a movement that redefined the way architecture perceives history, is no longer interpreted as an intellectual problem, neither is it a stylistic question, it is indeed a phenomenological experience led by accident and performed in a planned space. This process affects both society and individuals as architecture extends its responsibility to the orchestration of a coherent communication structure that is in permanent metamorphosis as it extends itself from the first shelter (past) to the last refuge (future). Architecture as an object evolved to a way of communication of heritage, customs, and history to the present and future society.

From the first dwellings of men to the more collective urban shelters, it can be recognizable that it is the population's interest to colonize and define their space through individual or collective cultural manifestations. In the first caves that men occupied, one can see art as a manifestation to personalize and narrate the daily life of the community and its individuals. Art can influence the way one lives a place and therefore become a pigment in our urban heritage. These marks of self-aware presence in space create different universes through phenomenological and consciously cultivated places.

Both Rossi and, later, Frampton identified that urban form is made by other layers of form and that none of this element is static as it evolves through social, economic and political factors[13]—and most of all by manifestations created by its users. These layers contains the collective memory that connects between themselves, therefore the evolution of the urban space evolves with society and vice versa. The shape of these urban boundaries differs in dimension, they relate to the phenomenology of human life, and they change translating the human condition at the time.

Rossi claims that the study of the city is only possible by converting it to its primary elements and refers to the *Genius Loci* of these elements as a connecting thread between different times and social memory.[14] The phenomenological act is the maintenance and interpretation of *Genius Loci* and the base for place creation and transformation, urban evolution, and—consequently—a writing of social memory and heritage. This principle comprehends the notion that urban space is both an accident and a practiced architectural matter, connecting the different eras of society. Studying the urban transformation of today's different known contexts, one can understand that phenomenology is intrinsically connected to communication.

The creation of different boundaries and the intervention of urban morphology are phenomenological manifestations that intend to communicate either individual or social consciousnesses. Unlike in previous social eras, when heritage was more defined by the author of the space planning rather than the future user, today we seek to leave our contribution in urban space and every small or simple urban action is either accepted, forgotten, ignored, or disapproved. Occupation and manifestation play the most important role in urban communication as they give new meaning to space function and material skin covering.

Places become more ephemeral and are created or transformed through the will of people to give social functions or new modular values to them, creating new spaces and restructuring urban morphology. These places are chosen through social identities hence the creation of boundaries where different users communicate through different ways, although this sometimes gives a fugacious attribute to space. Urban manifestations from leisure to artistic create new universes within a space, giving new permanent or temporary functions to a place through addition or subtraction, rewriting its identity; therefore, rewriting the script of its social memory and heritage. One thing is certain today: urban places are becoming more ephemeral and multifunctional.

The Planning, the Living, and the Digital

Ontologies in Architecture and the Urban Planning

Urbanism and architecture-driven ontologies are created to assimilate and dissect different data features to find common information links that create groups of agents in the urban environment. Through the study of gathered information, one can observe how the urban places evolve on a daily basis and we can make up nodes on urban space based on different chosen filters.

Ontologies play an important part in development, analysis, and understanding of the urban space as they can provide knowledge that was never before accessible. Being that architecture and urbanism are disciplines that are meant to serve and to benefit human life and that code must not be broken or corrupted, it is imperative that the gathered information on subjects is dealt with security and privacy. These methods can be used for some non-ethical work so information must be protected at all times and the privacy statement may not be infringed.

Today, over social media, for example, one can gather information on different subjects telling us their last or most frequently visited places and create different nodes based on different filters added to that information.

Ontologies in urban studies can be created by mixing different software like CAD (Computer-Aided Design), GIS (Geographic Information System), GPS (Global Positioning System), RS (Remote Sensing), and CAM (Computer-Aided Manufacturing) and using different means to achieve different objectives.

One popular example of ontologies in urban planning is PGIS, or Participatory GIS, a practice that has fused Participatory Learning and Action (PLA) methods with Geographic Information Technologies (GIT), promoting public participation in the geographical and morphological study of urban spaces. PGIS practice aggregates within itself several software made for geo-spatial information management like GPS and GIS, studying people's understanding, interaction, and communication with their environment. By promoting the public participation, this practice stimulates the users to share information, to learn, to question, to debate, and to participate in community decisions based on spatial information.

Using PGIS, it is possible to provide real time data regarding urban events to citizens. In the publication of her work, *From Local Knowledge Mapping to a Learning Planning Process*, Rantanen suggests that place knowledge and urban planning should be divided into two different contexts that go hand to hand, informal and formal information.[15] The first one, informal information, is said to be produced by the users and formal information is institutionally processed information.

The user experience of the place provides, in the age of communication, a far more important knowledge of the place, lacking the tools and discipline of the architectural practice, both combined become a harmonic planning force. Rantanen mentioned an exercise that proves her statement by selecting the neighborhood of Maunula in the city of Helsinki as a case study.[16] This city quarter is selected, being an example of population participation in urban matters and place planning.

Rantanen describes an experiment involving a handmade map incorporated in the innovative city quarter's website and providing local information while interacting with the population.[17] Users, which were later ordered by gender, age and residency, marked and commented on different urban places, classifying them as enjoyable, not enjoyable or unsafe, creating data that was later processed and presented with the possibility of filtering it by the previous classifications and subject category. Besides the overwhelming social experience, this proves that people are capable of understanding places of different shapes and sizes, as well as different universes within the urban space.

It is known that software technology is influencing the present era of urban life and planning as much as the Industrial Revolution has done in the past.

In the book *Smart Cities: Big Data, Civic Hackers, and the Quest for a New Utopia*, Townsend studies the circumstances that have shaped the evolution of urban space since the Industrial Revolution of the 19th Century until todays software technology.[18] It is a statement to say that communication is a major factor in city evolution; after all, the telegraph and the mechanical tabulator were major factors that constrained urban development. Townsend uncovers different applications of software used today in urban design and activity creating new horizons in architectural ontologies.[19]

Zaragoza, in Spain, is certainly an example of technology being used to facilitate urban life, as a citizen can use their citizen card to get different services like free urban Wi-Fi and paying for transportation. Chicago and New York are examples, given by Townsend, where GPS and RS software are used to provide information and coordinate urban events, either by showing a map that tracks snow plowing in real-time ("plow tracker") or detecting storm water flooding and opening new waterways to keep the flow.[20]

Today, architects and urban planners can actually observe and understand how people use spaces and create different places (universes), instead of just theorizing on what it is that makes urban places attractive or favored by users.

Communication in the Age of Urban Plasticity

Creating urban data using software is a promising way of resolving social issues regarding the use of space, if one can only find a way to discharge the complications regarding the economic and technical expense of creating and maintaining these applications and make them available to every user. Another problem of this new software age is the fragmentation of purposes as there are many programs developing unique or replicated solutions and there is no continuity and purpose aggregation within the different solutions.

The gathering of digital maps and georeferenced data can be produced through online experience as this is a communicational vehicle available to most people. Geographic information systems software, for example, are crucial to encourage a more active future participation of users in future urban planning, however for this to happen software must be presented in a simple form in order to make it available for everybody, including unexperienced software users.

Discussion

Merging institutional and user communications, one can provide to the urban space real solutions that contribute with relevant, definitive, and framed jobs to their agents. As architects and urban planners act as moderators and creators of conditions, institutions shall continue the administrative management of the urban space and users shall provide the ephemeral and permanent phenomenological aspect. Understanding the customization of places and creation of different universes, one can understand that people's experience of space is seeking this transformation. The National Association of City Transportation Officials (NACTO),[21] a "non-profit association that represents large cities on transportation issues of local, regional and national significance," discusses the way streets, as places, can be reinterpreted and promote safety within urban transportation by understanding the volatile aspect of urban transformation in our era. Streets are understood as a livable urban place, fragmented universes and not just traffic channels. The cult of space through urban traffic planning is detailed in the book *Urban Street Design Guide* by claiming that streets should have enough space to promote circulation, parking, shopping, bicycling, working, and leisure as designed moments in urban planning that create the base for the phenomenological spirit required to create place identity.[22] Urban space is not interpreted as static as, on one hand, old spaces need to be reconfigured to include them in a new period and, on the other hand, people should intervene in urban spaces through ephemeral and concrete metamorphoses that keep the space energetic with urban life. Parklets installations, graffiti, exhibitions, sculptures, outdoor cinema sessions, and theaters are some examples of urban users' initiatives that appropriate places and create universes giving new identities to urban life. This appropriation by groups of individuals or networks becomes part of the place heritage and it is a written manifesto; it goes hand to hand with the need to communicate with others and express ourselves.

Schacter's book,[23] *The World Atlas of Street Art and Graffiti*, studies the diffusion and history of graffiti while exposing its social meaning behind the art and how it evolved from the first gang-related graffiti to the contemporary art. This art form has evolved with the urban space itself; historical context is imperative to understand the urban phenomenology that is graffiti in the process of communication. The concept of graffiti as art form and appropriation of space explains the relationship between men and their habitat, the urban space. This is explicit in the book, suggesting that the urban artist work and life is deeply connected to specific places.

Previously referred to software applications in an urban scale are a way of creating data that gives us insight on the past, present, and, possibly, the future evolution of places and urban planning as it becomes more accidental and phenomenological. By collecting, studying, and understanding different data one can consolidate and plan a better human habitat through the practice of a knowledge-based constructed environment.

Local digital maps and georeferenced data needs to be associated with the community not just by studying it, but by providing the tools for man to write his own history, participate in the making of his habitat, and facilitate the building process of urban spaces of every scale. Architect's discipline is nowadays all about networks and communication transmitted from individual to individual, from individual to place, and from place to place creating new urban identities and networks through phenomenology.

Notes

1. Le Corbusier, "La Charte d'Athènes," *Fourth CIAM. Congrès Internationaux d'Architecture Moderne*, Paris, 1933.
2. Christian Norberg-Schulz, *Genius Loci. Towards a phenomenology of architecture* (New York: Rizzoli, 1980).
3. Aldo Rossi, *The architecture of the city* (Massachusetts & London: The MIT Press Cambridge, 1982).
4. Kenneth Frampton, *Modern architecture* (London: Thames & Hudson, 1992).
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7. Iñaki Abalos, *The good life. A guided visit to the houses of modernity* (Barcelona: Editorial Gustavo Gili, 2001).
8. Abalos, *The good life*.
9. Frampton, *Modern architecture*.
10. Frampton, *Modern architecture*.
11. Frampton, *Modern architecture*.
12. Kenneth Frampton, "Technoscience and environmental culture: a provisional critique," in *Writing Urbanism*, eds. Douglas Kelbaugh and Kit Krankel McCullough (New York: Routledge, 2008): 333-44.
13. Rossi, *The architecture of the city*; Frampton, "Technoscience and environmental culture."
14. Rossi, *The architecture of the city*.
15. Heli Rantanen, "From local knowledge mapping to a learning planning process," Finland, 2013: 4-6.
16. Rantanen, "From local knowledge mapping to a learning planning process."
17. Rantanen, "From local knowledge mapping to a learning planning process."

18. Anthony Townsend, *Smart Cities. Big data, civic hackers and the quest for a new utopia* (New York: W.W. Norton, 2013).
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21. National Association of City Transportation Officials (NACTO), *Urban street design guide* (New York: Island Press).
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23. Rafael Schacter, *The world atlas of street art and graffiti* (London & New Haven: Yale University Press, 2013).

CHAPTER FOUR

TYPOLOGICAL PROCESS IN MORPHOLOGICAL ANALYSIS OF EXTENSIVE URBANIZATION AT THE LIMA RIVER VALLEY

PAULO VIEIRA

Introduction

The morphological reading was developed with the purpose of providing professional reasons to describe and understand a territory outside the consolidated city.

The analyzed territory, by its very nature, does not fit in common morphological analysis methods (which tend to gain universal status of school or tendency) applied and reapplied (with some variation) to a great number of cities. This kind of territory—the coastal Minho region—most times is designated as "dispersed" or (in the best case) as "low density." Furthermore, in other occasions, it is associated with less favorable concepts like "chaotic," "disorganized," and “unexplainable" (and so on). Therefore, it requires a specific approach that considers, as a starting point, the observation of the territory in order to give a more fitting answer according to its specificities.

The terrain/climate’s morphological characteristics—together with the kind and intensity of human action over the land (towards agricultural use), the high population density, the very small plot size, the dense access roads’ network—lead to a formal detailed analysis. The goal was an accurate expression of territorial structures, achieving a framework of its production within a constant rewriting over the same medium (in a unidirectional construction)—insofar as it adds without erasing the prior elements.

Regarding operative terms, the landscape was divided into two parts: parceled land and land not parceled (concept to be explained later)—considering, for developed land, its breakdown according to processes proposed by Solá-Morales (1997) – urbanization, subdivision and building – although in this kind of landscape the subdivision and building processes are dominant in the final outcome. As Solá-Morales (1997) states, this is an analytical step, which although has a cost which reduction to schematic always involves, on the other hand shines a theoretical light to the knowledge and form project. This author also add that the form of cities as such are too often subject to a subjective or literary approaches.

As a method, we looked to develop a "caption," a reading key adequate to the present moment's representation of variables, and of the multiplicity of elements and processes to make possible its identification and description as well an adequate form to its representation. As a result, the analyzed territory would be expressed in maps, graphics, tables, etc., adopting the creation of several "layers," which would provide autonomous thematic analysis and would allow cross readings. Simultaneously, and considering that the purpose of this work was to measure and generate indicators that could back territorial planning and land management options, the research led to the choice of a territorial information system as the operating tool.

Establishing Basic Morphological Classes

According with the assumptions mentioned on the previous section, the morphological classification of the analyzed territory is based in the identification of processes of control/appropriation and development of the land considering its land use. In recognizing the pertinence and applicability to this territory of the conceptual approach by Solá-Morales (1997), his words can be adapted to this case when he highlights the relevance of infrastructural form (road paths, service networks, water edges, communication nodes, major accesses) as independent forms of plotted land which configure the land form with all diversity of shapes systematic or haphazard, of geometric composition or by repetition, or dependent of its previous topography, agricultural or property structure. In this sense, we start identifying the land using two basic morphological classes considering formal criteria: *i)* parceled land, *ii)* land not parceled—to which we add a third of functional type, *iii)* land assigned to infrastructural systems. Therefore, the core morphological classes can be set as:

- Parceled land (processed/developed), where it is possible to identify individual parcels through their material limits, (walls edges, terraces, fences, vines, etc.), which set restrictions to free access, or from soil preparation to activities implying frequent access (handling, cultivation).

- Land parceling is, or was, associated to any kind of use, usually agricultural, which gave rise to construction of an access system (roads, streets, paths rights of way, etc.) whose characteristics and infrastructure level can vary widely.

- Land not parceled where the plot is not formally materialized because either it is for public use or limits are inadequate or not relevant to its use, and where continuity is a dominant feature.

    - These areas can be the subject of processes by which they acquire a productive character, like forested areas, or remain untouched (natural), like the seashores, river network associated corridors, high elevation areas, or steep hillsides.

        - Land assigned to infrastructural systems, occupied by the access systems (mobility, logistics) and functional support of the territory (water and energy supply, storm drainage, and waste disposal).

Figure 04.1
Neiva River valley plots (drawn over orthophoto), Viana do Castelo.

Representation Procedure

Since it was not the purpose to go into a formal process of graphic land representation, it was decided to use a simple process of representing the land parcels over an orthophoto base map, using closed polygons. To do it, it was considered for parcel representation: *i)* the walls, *ii)* the embankments, *iii)* vines terraces, etc. It was also considered important to take time to understand the character of the closed polygons as defined by their relation to the terrain, as represented by the contour lines, and the non-parceled land, which (in this particular case) corresponds to the right of ways (paths or roads) and their widening (squares or plazas). The subsequent representation obtained by the applications of these core concepts shows: *i)* that it is possible to establish a clear distinction between the areas of manufactured land, towards its use, and the areas where human action over the territory is less intense on because of that less endowed with form; *ii)* that considering the parceled land area, registry forms tend to cluster, assuming vaguely honeycomb-like structure, almost resembling a sort of pre-urban block, between the path network; *iii)* that all the parcels of this mesh have access from this honeycomb-like network, ensured by a subdivision process at right angle to its access; *iv)* that the size and configuration of these parcels is closely connected to the terrain and local hydrography.

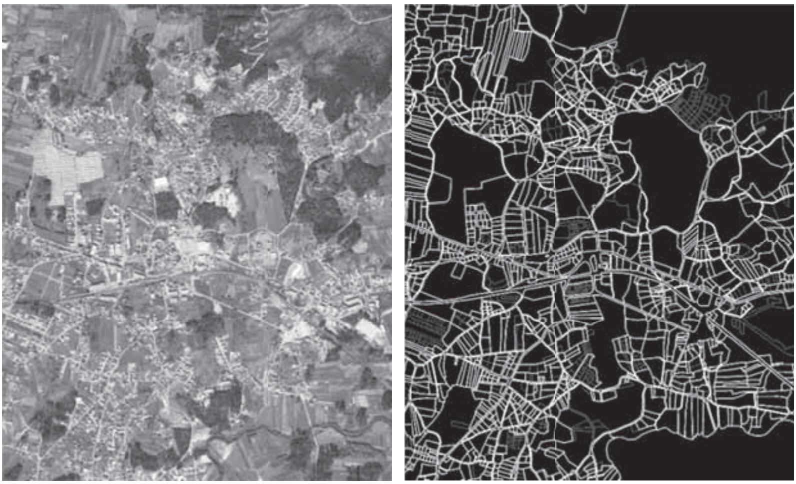

Figure 04.2
Neiva River valley orthophoto (2014) and its plot representation (over 1989 (lighter) and 2014 (darker) orthophotos).

The comparison of the parcel representation at distinct moments, by using orthophotos of 1989 and 2014, enabled to reach the following conclusions: *i)* the existing rural path network in the older representation was the basis for the dispersal and subsequent densification; *ii)* consequently, the growth of the road and local accesses is greatly reduced, and most of the additional investment made consists of widenings and occasional path corrections; *iii)* the size of the more recent building plots is smaller, reflecting the abandonment of subsistence agriculture and associated farmhouses.

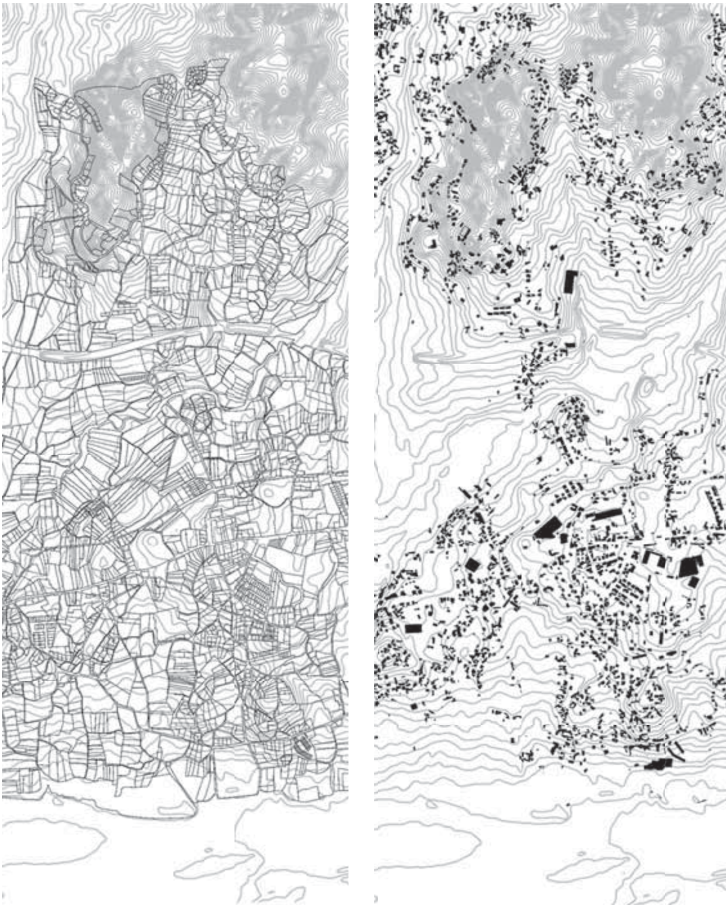

Figure 04.3
Northern bank of the Lima River and its plots (drawn over the 2014 orthophoto) and 2014’s buildings (over contour lines), Viana do Castelo.

The analysis of different parts of the territory with different characteristics and the insertion of buildings brings light to some issues: *i)* the areas where the parcels are of smaller size (due to increased subdivision) also correspond to the more densely built areas; *ii)* building distribution is very sensitive to terrain, forming a belt around the steeper areas (northern part of the last Figure); *iii)* there are points in the territory (in this case, the intersection between the main east west road and the north south access to river pier) that exert a polarizing force, in turn favoring greater typological diversity and the clustering of bigger buildings; *iv)* motorway introduction corresponds to a higher level of morphological breakdown when compared to the surrounding parcels, causing significant morphological and landscape changes (embankments, earthworks, overpasses).

Topic A

Processes, Typologies and Components of Parceled or Processed Soil

With the purpose of clarifying more effectively the relationship between the operating activities in the territory and the resulting form, the varied morphological typologies were grouped according with type of land processing and use. In other words, according to the different forms of relationship between *I* (infrastructure), *P* (parcel) and *B* (building).

Again, having Solá-Morales (1997) as a reference, using his words, it can be said that the building of a city is subdivision + urbanization + building. But these three operations are not isolated acts nor are they always linked in the same manner.

On the opposite, it is in the many forms they combine in time and space that the morphological richness of the cities has its origins. Although we proposed a reading key for the whole territory (parceled land, not parceled land, and land assigned to infrastructure), we shall describe only the typologies relating the parceled land. Being the more complex area, given the overlaying and concentration of processes, the search for analysis methods that favor its understanding is the more rewarding.

Topic B

Built-Up Land: Consolidation/In-Fill Typologies

These are typologies related to a rural model of land occupation, referring to a context of high building concentration in the traditional city, and of dispersed built occupation, supported by an access network of capillary type, which spreads along the edges of productive areas situated in the strip of land straddling the boundary between plain and hillside. It is a structure that was generated and that supported a society based on a rural economy, with components spread over the territory, thoroughly using the available arable land in which every house (and its dependencies) constituted an autonomous micro centrality (which, in bigger estates, possessed its own private worship place). They assumed the role of spatial reference to the organization of daily life going beyond being a place of shelter for humans and animals but also of processing, storing, and consumption of products. In these units—once functioning as manufacturers of landscape in the way they favored the use of the territory in more extensive fashion than today (where the need for mobility lead to a greater attraction power to roads, generating wider amplitude of land use intensity)—can be found the basis for an economic model. It involved intervention over forested areas, agricultural areas, paths and access network, water network, etc.

Typologies were related to the traditional city within a consolidated and stabilized process (spatially delimited), showing building densification processes without significant structuring actions: *i)* free plot occupation; *ii)* substitution of lower building density types; *iii)* occupation of free areas as the result of dislocation of previous activities. Concerning urban nuclei, also within a stabilized process, the relevance of building clusters forming small nodules in the road network (in a row or irregularly groupings) of semidetached housing directly facing the streets, usually small, can be mentioned. These nuclei sometimes have an occasional character, springing up near road junctions, giving rise to small irregular squares for public use, or spreading themselves along the paths. About the rural unit (farm), as a finished process, it implies settlements built with the purpose of occupying and putting the territory to agricultural use, combining the housing function with the agricultural functions, as well as the storage and processing of the resulting farm products. It is a complex built structure encompassing housing areas, animal dependencies (stables, corral), product processing places (wine and oil presses, threshing floors), storage places (granaries, winery, haystacks), but with a stabilized and repeatable program. It appears in isolated form or in small clusters.

Topic C

Built Land: Growth Typologies

Subsequent urbanization typologies to the territorial rural occupation model, involving densification and growth, are supported in the constituent elements of the vernacular structure identified earlier and which end up serving as a basis of the occupation and densification of the last decades. The territory is occupied, in general terms, in an extensive way, like it was before, more densely (in built areas mainly) but, above all, much more engineered, with practically universal access to mobility, infrastructures, energy supply, and information networks. The identified sorts of growth typologies were as follows:

i) Linear growth (operant process)—sequential building construction along an existing road. It can assume the shape of a somewhat systematic real estate development, depending on whether it adds new road infrastructure or builds in pre-existing parcels along roads.

ii) Growth through densification-informal-stabilized process-occupation of parcels non-adjacent to the local road network, instead supported in purpose-built occasional accesses. As examples, we have self-construction areas, building processes that result in extra buildings inside the same parcel, using the same access to the public right-of-way. They can also take the shape of informal neighborhoods or luxury condominiums. They occupy higher elevation areas or small hills in order to preserve agricultural land. It encompasses densification processes, giving rise to recent buildings supported in existing structures, but typologically and functionally different.

iii) Growth through densification-planned (operating process)—urban land promotion by more complex subdivisions than the above mentioned, results in infrastructure construction (roads, utilities), public facilities, green spaces. Building programs consist of detached housing with a private yard; although, either higher intensity processes may occasionally spring up—row housing or apartment blocks with the ground floor for commercial/service uses. In some cases, through a consensus building process, different contiguous developments can have somewhat functional or less frequently formal coordination.

Topic D

Extra Built-Up Land/Dissonances

The resulting landscape of the processes described until now when looked upon from, say, an elevated point presents a homogeneous appearance, though you can discern some rhythms and typologies which confer the character that resembles a patterned overlay, the resulting regularity being the outcome of the repetition of detached housing either of one or two floors with a private yard. Nonetheless, occasionally out of this pattern, because of either the greater size or higher building volume, some operations stand out, constituting dissonances to the general reference picture. The typologies on this topic are as follows:

i) Monotypes (operant process)—buildings that have some difficulty fitting other categories due to morphological or formal causes (bigger size, punctual relationship with its access, specific architectural language), and typological causes almost always due to function related reasons (public facilities; tourist oriented developments; production units, industrial or agricultural; storage, or facilities associated with territorial infrastructural systems; etc.).

ii) Emerging buildings (operating process)—interventions characterized by a punctual rise in the intensity of the urbanization process, in a given place (building area concentration or function siting that promote greater user inflows), originating volumetric or typological discontinuities, often even ruptures, standing out from its surroundings.

They do not look to locate themselves for reasons intrinsic to the place (such as agricultural units or ceramic factories) but look for advantages that derive from their geographical positioning due to accessibility or housing price/quality ratio. These interventions spread some urban characteristics throughout the territory (emerging of commercial functions or service offerings) and may serve to enable subsequent densification processes.

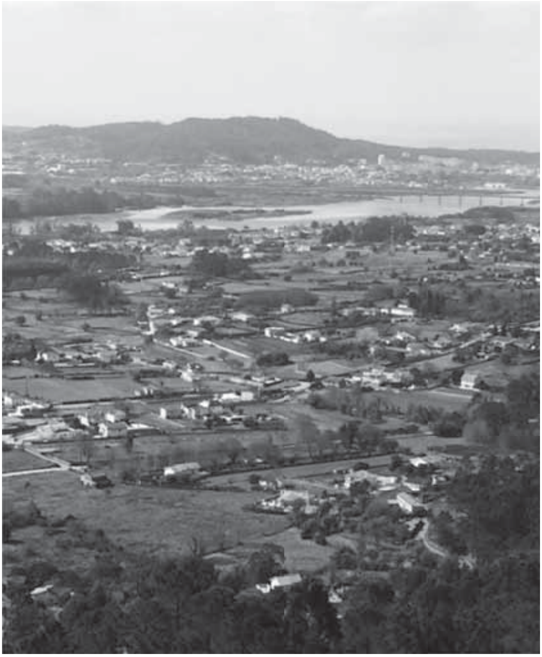

Figure 04.4
Northern bank of the Lima River (2016), Viana do Castelo.

Topic E

Non-Built-Up Land

Subdivided and infra-structured land is used for functions that do not entail building construction or are apt to host building construction. It consists of parcels or plots located in urban and built-up areas in general terms, but where the building has not taken place yet. Identifying and measuring this land, namely the expectant plots, may be of great use in the review of territorial master plans due to the contagion in the present discourse of preconceptions that served to enshrine the dichotomy between urban versus rural land in the territorial master plan framework legislation. Moreover, it is also important to refer to the internalization, by most agents, of the belief that reviewing the master plans will serve to reverse a great share of urban land into rural land. Within this framework, the typologies to be mentioned towards this topic enlightening are as follows:

i) Zero elevation building—delimited plots with controlled access where the land has been prepared to perform a function that eliminated the possibility of belonging to natural or agricultural land (cemeteries, sports pitches, paved enclosures destined to particular uses [parking, fairs, freight parks]).

ii) Expectant parcel—parcels or infrastructure subplots where building has not taken place yet. In the particular case of parcels, an infill criterion will be applied considering the surroundings and checking the building occupation of similar size parcels; the identification criterion will be even more narrowed down, the bigger the knowledge of the existing infrastructure in each site.

Figure 04.5
Northern bank of the Lima River, Santa Marta do Portuzelo (orthophoto, 2014), Viana do Castelo.

Figure 04.6
Northern bank of the Lima River, Santa Marta do Portuzelo; application of the interpretative key.

Topic F

Agricultural Land

Parceled and accessible land without buildings is developed with the purpose of supporting agricultural pluriculture with simultaneous cultivation of produce, wine (in suspended structures, over rocky areas or watercourses, or delimiting the parcels or fruit trees). Recently monoculture can be found, namely vines, this time with ground up vine training, and maize due to the high intensity of dairy production. About this topic, the categories are as follows:

i) Traditional—low intensity production in pluricultural system (without intensive mechanization) for self-consumption.

ii) Intensive—encompasses market production systems employing technology and mechanization, production of single crops (monoculture), and integration in logistics chains that allows access to markets, using infrastructure, utilities (water and energy supply, disposal, and treatment of waste), and built structures (such as greenhouses, warehouses, cold storage, etc.). Vine and maize are the dominant crops but, occasionally, one notes the use of greenhouses to raise produce, ornamental plants and floriculture.

iii) Non-cultivated—parcels which even though are bounded (have a formal presence), are no longer being put to agriculture use.

To summarize the previous topics, we considered the following table:

core morphological classes	process	typology	components
parceled land access control/ materialized limits	built-up land – consolidation	traditional city	infrastructure + parceling + building
		urban nucleus	
		rural unit	access + agricultural parcel + building
	built-up land – growth	linear	parcel/plot + building
		densification – informal	access + parcel + building
		densification – planned	infrastructure + plot + building
	extra built-up land – dissonant	monotype	infrastructure + parcel / plot + building
		emerging	
	non-built-up land	zero elevation	pavement
		expectant	infrastructure + parcel/plot
	agricultural land	traditional	access + crop
		intensive	access + crop + built structures
		non-cultivated	access
inaccessible/non-materialized limits	natural	natural corridor	water course + vegetation
		natural area	natural Cover
	productive land		culture

<table>
<tr><td rowspan="5">land assigned to infrastructure systems

access, support and functional systems</td><td rowspan="3">right-of-way – integrated</td><td>arterial network – rural</td><td rowspan="2">path+ street + square + plaza + …</td></tr>
<tr><td>access network – densification</td></tr>
<tr><td>roads</td><td>road</td></tr>
<tr><td rowspan="2">right-of-way – segregated</td><td>tunnel type right-of way – motorway</td><td>road + nodes + embankment + gas station+ …</td></tr>
<tr><td>railway</td><td>rail track+ railway station + rail freight terminal + …</td></tr>
</table>

Figure 04.7
Morphological classification.

Discussion

About the Methodology

The developed formal interpretative key enabled the classification of the whole territory accordingly with morpho-typological criteria in a satisfactory way. However, the proposed reading of the territory has not been thoroughly explored, which makes clear the need to “tune-up” its application, namely in the transition from parcel to built-up classification, due to the large diversity in parcel size, which will enable, without questioning the core precepts, a clearer representation and results. The distinction between the two core morphological classes enabled a solid conceptual advance in the identification of study areas outside the consolidated traditional city, onto which it is possible to adopt analytical approaches, supported in methodologies of a formal morphotypological nature, which can adequately frame spatial planning and management of the territory.

Parcel representation showed itself to be a tool of great use in understanding and in the description of territory constituting a layer of great formal consistency, a “board” over which land production is played, for the benefit of diverse activities. The access served parceled land area has not increased, even occasionally diminishing due to the abandonment of cultivated areas in the fringes. Nonetheless, punctually (mostly along road axis) densification and intensification of urban processes do occur. In these areas, one can ascertain a greater diversity of processes and typologies embodying the coexistence of diverse logics of urban land production in simultaneous operation (urban nucleus expanding in linear form along existing roads—

usually through the construction of detached or semidetached housing—and in between host planned densification operations-subdivisions). It is also in the same areas in which monotypes (public facilities) and emerging buildings (apartment blocks with mixed use) tend to cluster. One can discern the great persistence of the road paths, the great degree of parcel fragmenting, and the physical possibility of building almost everywhere. In many cases, it happens directly with the parcel transitioning from agricultural or non-cultivated to a built-up occupation (by the addition of a building) without having been necessary to change its shape, size, or existing infrastructure (access). On the other hand, the application of the methodology made clear the location of the urban nucleus of agricultural unit that, together with the access network, served as support structure to subsequent densification and expansion processes. It also became clear, on a wider territorial scale, that some morphological continuities are structural in character, namely unoccupied parcels or the prevalence of certain typologies along certain road axes together with their relationship with underlying morphological factors. Parcel and unbuilt/expectant plot identification showed itself to be of great strategic importance for the definition of spatial planning options. Namely, in cost estimation associated with urbanization and building processes (which correspond to areas where only the building is lacking) because it allows the building potential of certain areas to be assessed, taking into account the investment needed to make it happen.

Spatial Planning and Managing the Territory

Considering the great importance of morphological issues in the planning process, the proposals for describing, interpreting, and assessment of the resulting forms of processes related to territorial and resource use can be a good contribution to establish a solid basis for the execution of a rigorous, competent spatial planning and land management work. In this kind of territory, one sees the coexistence of simultaneous activities derived from local specificities (a particular raw material, soil, prevailing winds, moisture content, etc.) with activities detached from those specificities, and anchored in logistical chains, mobility systems, production places, housing and consumption, technical know-how, etc., only dependent of the availability of high capacity roads, mobility or logistical infrastructure, or data networks. The transition from a linear and sequential society into a simultaneous and point-to-point society, in which the diverse dimensions and relationship scales operate in the same timeframe (hypertext society),[1] blunts the effectiveness of traditional spatial planning and management tools (based in projections and zoning) and associated regulation.

The predicted direction of the situation should lead the selection of knowledge, based on approaches to the territory and its specific dynamics, under pain of seeing the planning profession (as maker of formal plans) being relegated to an irrelevant role or, worse, an impediment that one tries workaround or ignore. An issue that, on this matter, stands out is that the legally available planning instruments (legal tools available) of mandatory use (in the case of the municipal master plan) in the planning, management, and land development process have showed themselves lacking when it comes to supporting the land development with quality gains. They start with normalization assumptions, of uniformity, of immutability and permanence, not to mention the technocratic apparatus that surrounds them and the bureaucratic procedure involved, which do not fit well with the variety, heterogeneity, and versatility that reality presents. Twenty-five years after the approval of the first municipal master plans in Portugal, it is pertinent to look at two of the main planning goals:

i) The demarcation of the urban perimeter (a morphological objective), on the back of a dual definition between urban versus rural land.

ii) The containment of its growth (operational objective), mostly achieved based on the definition of what Portas calls "No areas"—to realize its unsuitability to territories such as those studied here.[2] One must remember that the inhabitants of these places are also urban because, as Innerarity says,

> *the inhabitants of the city which move to the countryside, continue to being urban, because deep down there is city where there is the possibility of emancipation.*[3]

This emancipation is being assured by personal mobility and by the generalized access to information.

Notes

1. François Ascher, *Novos princípios do urbanismo* (Lisbon: Livros Horizonte, 2012).
2. Nuno Portas, *Os Tempos das formas* (volume II). *A cidade imperfeita e a fazer* (Guimarães: Edição EAUM, 2012).
3. Daniel Innerarity, "Las ciudades en un mundo globalizado: hacia una nueva forma de ciudadanía," *XII Encuentro de Planes Estratégicos,* Zaragoza, 2008.

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CHAPTER FIVE

THE STUDY OF NEIVA'S VALLEY COMBINING SPACE SYNTAX AND GEOGRAPHIC INFORMATION SYSTEMS

JOÃO PEDRO PASSOS

Introduction

The configurational analysis using techniques and methods of space syntax clears morphological characteristics of the studied territory, allowing a better comprehension concerning the functioning and liaison between urban form and social relationships involved. The correlation with an economic-spatial dimension approach, particularly with regard to its components and interdependencies, aims to know how to process the spatial appropriation within the urban area. The correlation of this approach with the methodology of space syntax helps to increase knowledge about accessibility levels of activity in the territory. Additionally, it allows obtaining more structured analysis that can support more technically robust decisions.

Neiva's Valley Territory, Viana do Castelo

The city of Viana do Castelo is geographically located in the North of Portugal (Alto Minho region) and is the municipality district capital of the same name. Its borders connect with the municipalities of Caminha (North), Ponte de Lima (East), Barcelos and Esposende (South), and the Atlantic Ocean (West). Viana do Castelo has an area of 319 km^2 and altimetry variation reaching difference in elevation of around 800 m. Potentially lower areas are located on the coast, by the sea, with a slight quota increase along the estuary of the River Lima, towards its source—as expressed in the topographic map. Neiva's Valley Territorial Unit occupies the southern strip/interior of Viana do Castelo County and is comprised of the parishes of Vila Fria, Alvarães, Vila do Punhe, Mujães, Carvoeiro, and Barroselas.

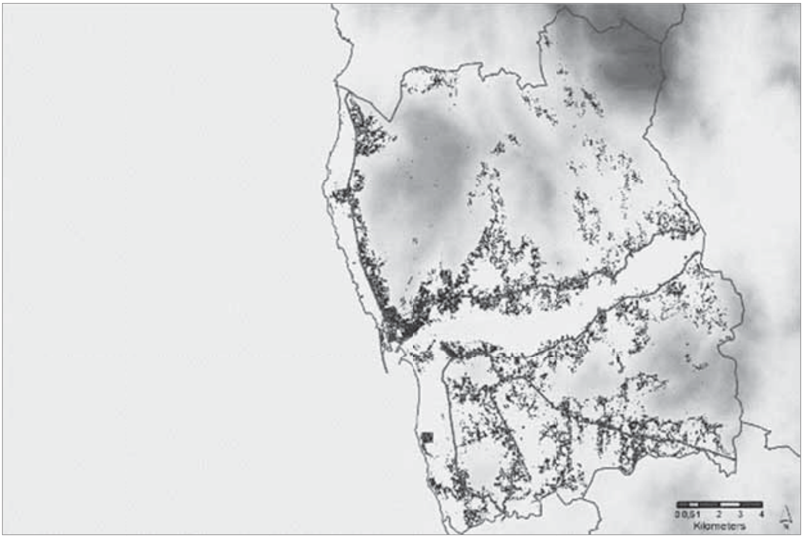

Figure 05.1
Structure and territorial organization map of Viana do Castelo.

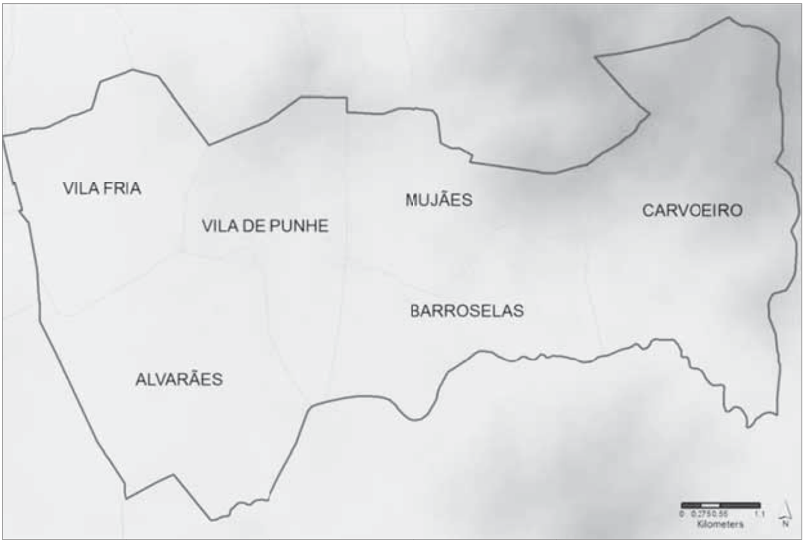

Figure 05.2
Neiva's Valley Territorial Unit.

Urban Configuration

The population density of Neiva's Valley Territorial Unit is about 278.11 inhabitants/km^2, in which stands the parish of Barroselas with a population density of 525.70 inhabitants/km^2. The constructed area occupies mostly the track between the mountain range (to the North) and Neiva River (South). It is a territory that is characterized by its economic dynamism, distinguishing the area of economic activities of Carvoeiro (in the East), resulting from expansion of Neiva's industrial zone (located to the West) and the mining activity (located in the same direction). Allied to these economic centers (of greater importance) are numerous small industrial units dispersed a little throughout the Territorial Unit, as well as in the neighboring villages of the districts of Braga, Barcelos, and Ponte de Lima. ER308 is the road that pierces the Territorial Neiva's Valley Drive, connecting Viana do Castelo with the Municipality of Barcelos, and on which is established much of the urban dynamics mentioned above. It is a pathway that is characterized by some constraints influenced by the pressure of the urban fabric.

Based on the methods and techniques of space syntax, the study sets the categories of analysis for Neiva's Valley Territorial Unit. Exploratory research, aimed at the correlation between the spatial and social standards, resorted to quantitative and qualitative research, considering four variables: *i)* shape and distribution, *ii)* density, *iii)* topological analysis, and *iv)* metric analysis. After the study of the urban configuration within Neiva's Valley Territorial Unit, one can understand that this territory has a frame structure that does not reveal great relations between villages. This alone is not synonymous with a lack of urban vitality of each village, but influences greatly on the quality of relationships between them. On the other hand, the analysis raises the importance of the structural axes, namely the capability to centralize urban dynamics.

The research didn´t focus on the study of a large urban center configuration (regarding its formal properties); however, space syntax methodology proves its importance, allowing the highlighting of the segregated nature of the territory and its uniquely local reality. The urban configuration influences the setting of relations, namely those concerning how to use the urban space, or even the form of appropriation of the urban grid. Accordingly, the results of the configurational analysis can be useful towards a more informed decision in respect of future local intervention strategies. Briefly, the analysis shows the urban form based on the quantitative and qualitative study.

An Integrated Correlation

Having made the syntactical analysis of the urban space of Neiva's Valley Territorial Unit, the correlation was also important with another morphological approach to understand the intrinsic complexity of this space system. It was understood that there was a correlation between the spatial and social patterns of urban space meaning that the urban setting benefited from the analysis based on the spatial appropriation of the urban grid.

The truly relevant question is whether space syntax allows an objective and detailed analysis with clear concepts and principles, increasing the capacity to set the true potential vocation of spaces, regardless of their current occupation. This is important when considering the theoretical framework to be developed to get results that are more accurate from measuring components in the field that helps to create a model to increase the predictive capacity and support for practical action due to a strategic vision.[1] The implied urban dynamics of these processes, such as the principle of natural movement,[2] is of crucial understanding to realize how far the presence of socio-economic patterns influence space dynamics. This point addresses the spatial economic issue in particular with regard to its components and relations, proposing to understand how it is processed in the spatial appropriation of the urban grid. It constitutes an approach based on spatial metrics and in a relational logic between indicators of the territory and the urban setting. It was also used in occurrences intensity maps (to show existing standards) using an 800m radius interpolation method and a representation of the occurrences on a cumulative sum system.

Occurrences means the survey and geo-referencing of the activities present in the study area. To establish a connection between both approaches, the research was based on fieldwork collection of data and processing information from the collected data. It developed a comparison between the processed information and its results interpretation.

Spatial Appropriation Analysis

This section reveals the developed study based on quantitative and qualitative methods, gathering indicators that were collected during fieldwork that emphasize the importance of certain activities in the territory. The analysis was set on geospatial metrics (and its theoretical framework), where they were best suited to measure and quantify urban spatial patterns.

Based on the processed information, a field survey of non-residential functionalities (ground floor level) was developed. It was considered the division of registration units, making use of information gathered *in situ* to develop the classification of different elements. The resulting categorization (Figure 05.3) targets to consolidate the collected data in a homogeneously, exhaustive, and exclusive process, fine-tuned and adapted to the purpose of the research.[3]

category	technical/ instrument	source	selection criteria
urban grid non-residential features	notes field notes	Neiva's Valley Territorial Unit, Viana do Castelo	EAC/Economic Activities Classification

Figure 05.3
Categorization methodology table.

After undergoing geo-referencing, the collected data was analyzed to generate information. ArqGis® software was used, supporting the fieldwork survey and providing a way to treat the obtained data. It is important to mention that the survey criteria did not discriminate the parcel character of land occupation. Functional survey categorization was useful to enable the identification of patterns in Neiva's Valley Territorial Unit. Within the categorization, a direct relationship between the activity and EAC/Economic Activities Classification was set. The purpose was to have a category homogeneous framework. As a result, 657 activities were collected, highlighting the presence of services, trade, and unoccupied areas, with 21.6%, 19.5, and 18.0%, respectively (Figure 05.4 explains this trend). Neiva's Valley Territorial Unit is marked by industrial activity with 13.2% of all occurrences—mostly, microenterprises. Figure 05.5 shows activities of different villages. The village of Barroselas reveals 269 occurrences, meaning 41% of all activities of the analyzed area. In turn, the villages of Carvoeiro and Vila Fria only have 8% and 10% of occurrences, respectively. The village of Barroselas has a prominent role throughout Neiva's Valley Territorial Unit. This fact greatly contributes to the strong presence of activities related to trade, services, and industry. The high rate of unoccupied occurrences compared to other villages should also be highlighted. Finally, the villages of Alvarães and Punhe each represent 15% of total activities.

activities	occurrences	%
trade	128	19,5%
unoccupied	118	18,0%
tourism enterprises	6	0,9%
social support facilities	9	1,4%
drinking establishments	45	6,8%
schools	14	2,1%
industry	87	13,2%
sports facilities	13	2,0%
house of worship	22	3,3%
others	49	7,5%
premises shows and entertainment	1	0,2%
restoration	9	1,4%
services	142	21,6%
health units	14	2,1%
total	657	100,0%

Figure 05.4
Non-residential survey within Neiva's Valley Territorial Unit.

activities	Vila Fria	Alvarães	Vila de Punhe	Mujães	Barroselas	Carvoeiro
trade	8	12	16	14	69	9
unoccupied	4	16	23	12	59	4
tourism enterprises	1	0	4	0	1	0
social support facilities	1	1	2	2	2	1
drinking establishments	4	5	14	5	15	2
schools	3	3	1	2	3	2
industry	10	17	8	7	26	19
sports facilities	2	3	2	2	4	0
house of worship	3	4	3	2	5	5
others	9	9	9	4	17	1
premises shows and entertainment	0	0	0	0	1	0
restoration	1	0	1	0	6	1
services	15	28	14	22	55	8
health units	2	2	1	3	6	0
total	63	100	98	75	269	52
%	10%	15%	15%	11%	41%	8%

Figure 05.5
Activities by parishes within Neiva's Valley Territorial Unit.

Regarding spatial distribution, Figure 05.6 discloses the location of activities in Neiva's Valley Territorial Unit. It is shown that, in most cases, the activities extend along the ER308, with higher intensity centers in the villages of Barroselas and Vila do Punhe.

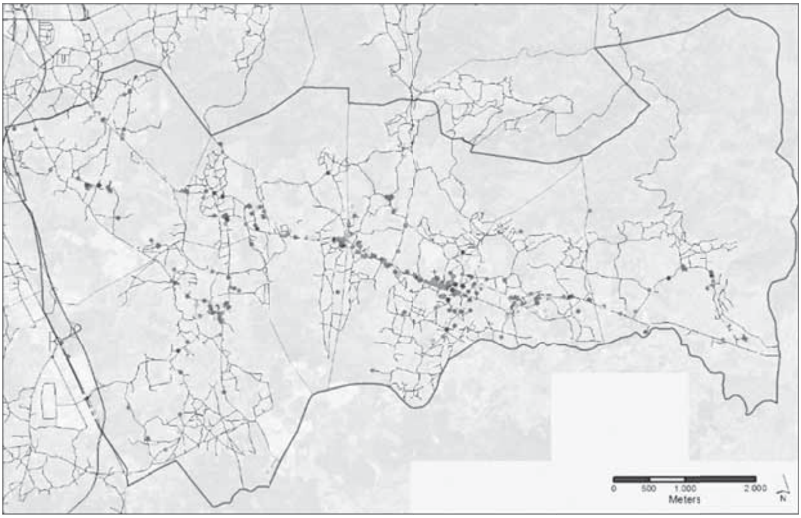

Figure 05.6
Overall distribution of activities within Neiva's Valley Territorial Unit.

An exception to this reality is the existence of an activity core in the urban centers of the villages of Alvarães and Vila Fria, indicating 30% of all activities in both. In these cases, it may imply the importance of proximity to structuring roads located in the North and West.

Space Syntax and Spatial Appropriation Correlation

In this part of the chapter, a correlation is explored between space syntax and the spatial appropriation of the urban grid. The correlation was performed by crossing the produced maps during the analysis and the production of schematic charts. This was considered as a representational tool and simulation process of the analyzed reality to simplify the formulation of the hypotheses. Thus, reality is transformed into an abstraction, preserving the representation of all the elements and their relationships. Regarding configurational analysis, the correlation was based on the accessibility potential, calculated on the average depth analysis, with a 1200-m radius metric choice. This choice, which represents a pedestrian route of 15 minutes, is justified in the chapter of spatial syntax analysis. This analysis is based on 17,486 segments of that system, which in turn are ranked among grade one and five by the potential for pedestrian choice of urban layout.

Concerning the analysis of spatial appropriation of the urban grid, the correlation is based on 657 indicators obtained in Neiva's Valley Territorial Unit. The correlation methodology consisted of overlapping resulting maps of the two analyses, proceeding to the quantification of appropriation indicators obtained in fieldwork, classifying them accordingly to the degree of pedestrian accessibility. Having made this methodological introduction of the correlation between syntax and spatial appropriation of the urban grid, now it is important to analyze the results. Figure 05.7 gives an overview of the location of different activities according to the accessibility characteristics of the urban layout at Neiva's Valley Territorial Unit.

Figure 05.7
Potential accessibility map of non-residential activities.

It possible to realize that most of the activities match with areas with a greater accessibility potential. Among others, the activities located along ER308 road, particularly in the village of Barroselas where the activities' core is not enough to fill greater accessibility, smudge. This fact may represent a possible potential activity fixation in an accessible territory. In addition, the urban core of Alvarães village represents a considerable amount of activities, but they do not overlap with the routes with the highest accessibility potential.

Analyzing indicators within percentage basis, one can recognize in Figure 05.8 that the indicators were distributed among the different villages and in the five potential accessibility levels. It should be highlighted that each expresses a sum of 100%, which indicates the sum of indicators of each village. It is also important to note that the column of the total relates with regard to the totality of indicators, regardless of their degree of accessibility. This percentage is used to indicate the activities for each village.

village/accessibility (15 minutes)	1	2	3	4	5	total
Vila Fria	25,4%	11,1%	36,5%	15,9%	11,1%	9,6%
Alvarães	15,0%	7,0%	31,0%	38,0%	9,0%	15,2%
Vila de Punhe	5,1%	9,2%	60,2%	17,3%	8,2%	14,9%
Mujães	18,7%	5,3%	34,7%	20,0%	21,3%	11,4%
Barroselas	9,7%	9,3%	21,2%	19,0%	40,9%	40,9%
Carvoeiro	40,4%	13,5%	44,2%	1,9%	0,0%	7,9%
total	14,8%	9,0%	33,3%	20,1%	22,8%	100,0%

Figure 05.8
Relationship between pedestrian accessibility degrees to each parish within Neiva's Valley Territorial Unit.

In all villages, 33% of all indicators have a degree three of accessibility, showing that most of the activities at Neiva's Valley Territorial Unit have an average degree of accessibility. This tendency tends to increase, since other indicators are mostly grades four and five. For the villages, Barroselas is the one with a higher rate, with 40.9% of existing activities with a degree of accessibility five. In addition, the village of Alvarães shows a good degree, with 38% of its activities with a degree four. All other villages have most activities at accessibility grade three. Theoretically, one can fit this analysis within the principle of natural movement. The results obtained suggest that the configuration of the urban space has a direct influence on the movement and promotion of urban flows, which consequently influences where to set activities in the territory. This sequence proceeds an inverse process; in turn, activities generate the appearance of movement, causing changes in the urban space configuration. The relationship between dynamics contributes to the area urban vitality.

In short, Barroselas village, in the Neiva's Valley Territorial Unit, is the one that contains a higher percentage of determined activities and is also the village that exposes their activities to a greater degree of accessibility. Another correlation that can be done is to check the accessibility potential of each category of determined activities. This analysis is able to express the degree of how easily a certain activity can be reached. Considering the obtained results, patterns can be identified leading to the recognition of configurational structure potential in order to provide attractors fixation opportunities. Figure 05.9 reveals the intersection between syntactic analysis and spatial appropriation of the urban grid. As mentioned, the activities that exists more within Neiva's Valley Territory Unit are services (with 21.6%) and trade (19.5%).

activity/accessibility (15 minutes)	1	2	3	4	5	total
trade	8,6%	8,6%	28,1%	22,7%	32,0%	19,5%
unoccupied	11,9%	11,9%	31,4%	26,3%	18,6%	18,0%
tourist enterprises, food and beverage	5,0%	5,0%	41,7%	20,0%	28,3%	9,1%
social support establishments	11,1%	11,1%	44,4%	11,1%	22,2%	1,4%
schools	28,6%	14,3%	35,7%	0,0%	21,4%	2,1%
industry	24,1%	14,9%	36,8%	11,5%	12,6%	13,2%
fuel facility	0,0%	0,0%	0,0%	50,0%	50,0%	0,3%
sports facilities	15,4%	0,0%	76,9%	7,7%	0,0%	2,0%
place of worship	27,3%	18,2%	40,9%	4,5%	9,1%	3,3%
others	21,3%	2,1%	27,7%	23,4%	25,5%	7,2%
precincts shows and leisure	0,0%	0,0%	0,0%	0,0%	100,0%	0,2%
services	14,8%	7,0%	29,6%	23,2%	25,4%	21,6%
health facilities	28,6%	0,0%	42,9%	14,3%	14,3%	2,1%
total	14,8%	9,0%	33,3%	20,1%	22,8%	100,0%

Figure 05.9
Relationship between pedestrian accessibility degrees and categories of activities within Neiva's Valley Territorial Unit.

Regarding accessibility of these categories of activity, trade shows 32% of occurrences in grade five of accessibility demonstrating that there is a fixation preference in most accessible urban layouts leading to natural movement (when it is said that configuration influences the presence of attractors).

In addition, the service category, although it contains most of the occurrences at level three, displays a high percentage in accessibility levels four and five. The same applies to the unoccupied category, with 31.4% of occurrences with a grade three. The categories of fuel facilities and premises for shows and entertainment, although with an accessibility degree five, don't reveal enough occurrences to have the same conclusion. All other categories have an intermediate degree of accessibility, especially the sports facilities with 76.9% of occurrences. Regarding the total percentages, most of the 657 registered activities have accessibility grade three. However, the predominant trend records in grade four and five, at the expense of others. However, it should be mentioned that 14.8% of all occurrences has a grade one accessibility. This fact could be hindering a favorable urban development, not improving the balance of the urban structure of Neiva's Valley Territory Unit within the role it fulfils in Viana do Castelo County.

Discussion

This chapter sets a correlation between space syntax and spatial appropriation indicators of the urban grid to identify the degree of accessibility of non-residential activities featuring the urban grid of the studied area. It can enhance the importance of this correlation, since the theoretical component is divided evenly using the measurement component field, resulting in a "reading" of urban dynamics.

Quantitative and qualitative indicators' analysis, using geospatial metrics, proved to be useful in the characterization of urban spatial patterns, with emphasis on the number of occurrences of trade categories, services, and industry. Spatially, the majority of cases have a strong focus on the main structuring road of the territory, the ER308, with greater intensity in the village of Barroselas. An exception to this fact is the presence of stronger core occurrences in Alvarães village. A note of relevance should also be made to the industrial activity, which occupies the Neiva's Valley Territory Unit in a much-diversified way. This fact shows the importance of this territorial area as a link of socio-economic relations between larger scale centralities, namely Viana do Castelo and Barcelos County.

Regarding the correlation of these indicators with the accessibility potential of the urban layout, it is concluded that the territory reveals overall mean values of accessibility being distinguished, above all, from the urban centers of each village. Of these centers, stand the villages of Barroselas and Alvarães where the configuration of urban space exposes a high potential accessibility to different activities, even leading one to believe that the territory has the structural capacity to provide fixation opportunities for more activities.

In sum, the correlation of the adopted approach is shown to be a valid methodology in understanding the intrinsic complexity of the space system. To achieve this level of knowledge it was essential to complement syntactic analysis with field survey of all non-residential features, using the Geographic Information System (GIS). Thus, the result of this analysis can be useful, from a practical point of view, for decision support since it is able to identify areas of Neiva's Valley Territorial Unit with a greater potential for movement, or even to identify the areas with the greatest potential to establish the different economic activities categories. The urban spatial configuration generates accessibility, resulting in integration and segregation hierarchies. Thus, the research provided activity analysis within better accessibility conditions and detected the territory structural potential regarding existing opportunities or to set more activities.

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– Part II –

To Higher Semantic Levels of Theories

CHAPTER SIX

DEPTHSPACE3D: A NEW DIGITAL TOOL FOR 3D SPACE SYNTAX ANALYSIS

FRANKLIM MORAIS

This chapter presents DepthSpace3D (DS3D), a digital tool for space syntax analysis in 3D spaces.

Aims and Importance

Space syntax is a set of methodologies with an underlying set of theoretical assumptions, with ancient roots in classical architectural theory, but developed in recent and formal languages since the 1970s. Although in dynamic progress, space syntax is already a proven and well-disseminated instrument in architectural and urban studies (A&US). Space syntax formal algebra is very high 'numerical calculus' consuming. It can scarcely be of any use without the availability of communications and information technologies (IT). With gradual dissemination of space syntax, user-friendly apps were born; therefore, demonstrating again the historical inter-influence relation between the tool and the product in human work. Previous work by the DepthSpace3D research team reveals weaknesses in current tools. In former research developed on specific domains of A&US using space syntax, the researchers of DepthSpace3D project have been able to confirm the value of space syntax in the analysis of A&US. Nevertheless, the lack of a powerful software tool with 3D space syntax analysis capability, not always, but in certain cases, has been the cause of some restriction in the deepening of the analysis. For example, the work of the global analysis of the town of Maputo, by Viana (2015),[1] with intense use of space syntax 2D tools, could not deal with the problem of altimetry, since Maputo is known for having a low town and an upper town. The same problem arises in Porto where the sharp altimetry of the town prevents better urban analysis.

In architectural studies, 3D studies could improve space syntax analysis results even more. In the intensive use of space syntax to study segregation and privacy in thirteen collective housing achievements in twentieth century Porto, Ruivo concluded that 3D analysis could improve the results.[2] Although space syntax 2D could deal fairly well with the interior of each home and the middle-scale urban environment, it could not manage the high-rise buildings as a whole, or the relation of the building and its near environment, treated as a unique domain of analysis. A 3D space syntax tool would be very useful in these situations. Global space syntax studies' development is limited by current state of IT tools. An enlarged sample of A&US using space syntax methodologies developed worldwide, reviewed by the team, shows that the great majority of studies using space syntax concern urban studies. Moreover, between the three basic models (spaces, axial lines, and graphs) axial lines is the most spread one. Of course, this reflects the merit of predominant analysis but also that other tools may be improved. In 2D, surface is a line and not a convoluted surface. Perhaps it can explain Via Triunfalis, but it is not at ease analyzing Roma's Piazza di Spagna or Porto's Torre dos Clérigos. In 2D, space is a flat surface and not a volume. Large variety of volume sizes and very dynamic volume geometries are difficult to analyze without volume consideration. There is another and very important aspect that has to be stressed: space syntax has created an impressive structured set of concepts relating Space to some of its functions—physical (for example accessibilities), in perceptive and cognitive psychology (visibility and so on), and society (segregation, privacy). Classical theoretical architecture is also involved in form, meaning, and aesthetics. If we want to follow the theory lessons about the value of the dynamics of volumetric space in architectural evaluation, a 3D approach will also be needed. The team is convinced that the use of DepthSpace3D app cannot only improve results of A&US but is also capable of opening new trends. For instance, the statistical analysis of space syntax studies can demonstrate that space syntax is very proficient in urban studies but is much less used in architecture. A good conjecture is that architecture needs the volumetric and dynamic perception some architectural theoreticians pleaded for. 3D analysis could very well be a powerful tool in formalizing the classical theoretical architecture concepts such as proportions and scales, hierarchy, or rhythm. "Monument" is another concept of classical A&US semantic that space syntax paradigm seems to be mature enough to formalize. Summing up: 2D space syntax analysis is appropriated for the majority of cases, but a 3D analysis can complement most cases, can be an invaluable improvement in others, and can even open new fields of research. 3D digital tools are needed.

Space Syntax Analysis

When the research team began the work on a 3D tool, it had no intention to discuss space syntax paradigms. However, it soon turned out to be evident that some fundamental concepts needed, not a global remaking, but some amount of "critique". It is well known in math that the growth in the number of dimensions of a problem is not a linear procedure. Many sorts of emergent issues arise. That is especially true when we are dealing with mathematical formulations of material processes in a geographical n-dimensional space. The Coriolis Effect is commonplace.

Conceptual Model

The basic assumption of space syntax technologies is that a language based in visibility can represent and then solve many problems in A&US (with regard to other languages—sociological, psychological, and artistic). Space syntax have a very rich set of concepts, constituting their connotational semantics. Nevertheless, although very rich and increased every day by the research labor, those concepts are generated from a very low number of primitives. We could condense those core ideas in this way:

- The space of the A&US under consideration is cut from the remaining world (of course with careful considerations on where to cut, which we will consider later).

- This space is divided in two sections: the active portion, where human activities are accomplished, and a set of closed 'black box' spaces that are obstacles to those activities.

- In space syntax's core formulation, the human 'activity' in the active space is reduced to one—visibility. Well, if we consider that we see different things in different places, we will have to consider one more activity—movement—although only where visibility is concerned. Therefore, a function relates any two points of the active space that can assume a Boolean value. If located in one point we can see the other, the function assumes "Yes" or "True." Otherwise it is "No" or "False." As, in our customary world, light travels in a straight line, this is the same thing as to say that there is a straight line between the two points that does not intercept any of the obstacles.

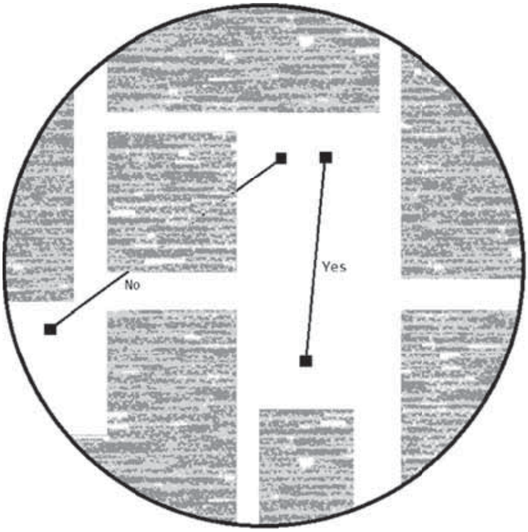

Figure 06.1
Visibility Function (Point1(X1,Y1,Z1), Point2(X2,Y2,Z2)) = Yes or No.

That Visibility Function will then be processed and will create very wonderful new things. In this first point of analysis, the transition from 2D to 3D made us critically review some concepts.

View Space & Viewed Space

One decision was to divide the active space in two conceptual different spaces. To view is a human activity; humans view the objects in the space. We consider two different spaces—the View Space (space that humans can occupy), and the Viewed Space that is offered to be seen by humans. We can enlarge that concept to other possibilities like video cameras. The traditional indistinctness of these two spaces in 2D analysis is easily understandable. As 2D flattens the world, the positions that humans can assume in the active space occupies all the space. The conceptual distinction can perfectly be lost in practical calculations. In 3D, the space potentially occupied by people is much smaller than all the space under consideration. This distinction is also assumed in 3D by practical considerations. As the calculation of the Visibility Function is very heavy in material resources (memory and computational time), any reduction of data is welcomed. Thus, this distinction obeys a better modelling of reality as well as operational needs.

Two Kinds of Viewed Spaces

The Surfaces & the Global Volume

In 2D, we have a Viewed Space (which is the same as the View Space, as we saw) that roughly represents the "ground" of the reality. In 3D, we must consider two types of Viewed Spaces:

i) The Global Volume—all the "air" that we want to analyze.

ii) The Surfaces of the objects that inhabit the global volume and are exposed to be viewed. This includes the "ground."

The 3D Surfaces are equivalent to the 2D ground (that in 2D constitutes also the completely active space, view and viewed) and also include, conceptually, the enclosing lines of the periphery of the "black box" obstacles. In 2D, they are not considered because their visibility is almost the same as that of the points of the "ground" just adjacent to them. In 3D, that is just not true.

The two sides of the Viewed Surfaces

It is not by chance that the 2D "black boxes" are closed. This restriction implies that their limits are seen only from one side. The consideration of open Viewed Surfaces comes with a penalty: the 3D Obstacle Surfaces have two distinct sides as visibility is concerned.

—Is the "air" of the Global Volume a Viewed Space?—

It seems clear that for A&US the Viewed Surfaces are very important. Nevertheless, the Viewed Global Volume is a novelty in 3D. Why do we need to analyze the visibility of the points in the air? Although it appears as less important than the Surfaces, the Global Volume may have some interest. For example, we can predict the visibility of something we will put in some location of the Global Volume, or it will help us to choose the most or the least visible location.

—The Obstacle Space—

Other than the View and Viewed Spaces, we will have the third conceptual space: The Obstacle Space. In 2D, the obstacles to visibility were closed "black boxes." This seems a good approach to reality.

In some urban studies, we do not need to know what is going on inside the buildings, and what happens visually inside a wall is scarcely important. Although we decided to create a more abstract representation of the Obstacle Space, it will be any surface, not necessarily closed. If we want a closed "black box," we can model it, in this more abstract paradigm, by a volume entirely closed by several surfaces and with no View Space inside.

Obstacle Surface = Viewed Surface?

They are conceptually different. They represent two different relations between the other concepts of the model (to be viewed and to be a visual obstacle). Nevertheless, it seems that they have the same object/referent in reality. What is the way we deal with this? Conceptually, the distinction is maintained. The calculations in the DepthSpace3D software will treat them in accordance. Although, in the data input, they are treated as the same thing to avoid the duplication of the generally heavy work involved, this solution is not without frictions, as will appear later.

The Visibility Function— from View Space to Viewed Space

The Visibility Function is no longer bijective but is always directed from the View Space to the Viewed Space.

—Visibility Function—

(View Point (X1,Y1,Z1), Viewed Point(X2,Y2,Z2)) = Yes or No

The following graphic represents our 3D conceptual model:

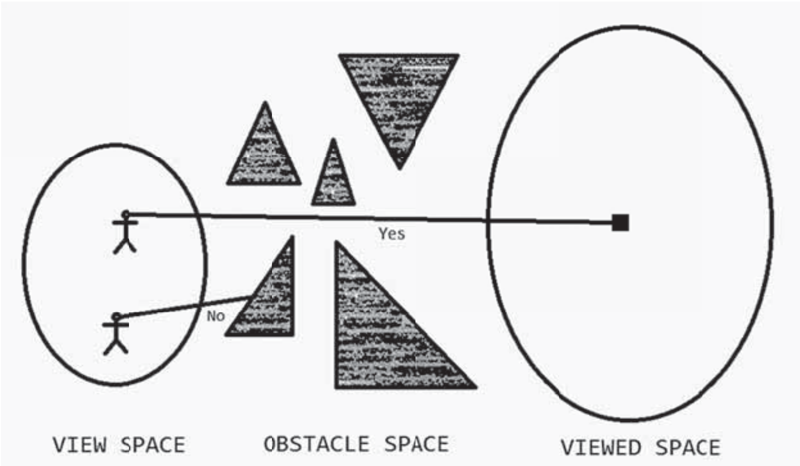

Figure 06.2
Visibility Function graphic representation.

Transparencies

Another feature of the program is the consideration of a certain degree of transparency/opacity of the media (the Obstacle Space from the seeing and seen objects). Visibility from the view space to the viewed space is no longer a Boolean quantity, but it is considered a continuous quantity varying from 0 (not visible) to 1 (full visibility). The model we use to give shape to this concept has to be easy enough not to pressure the already overloaded calculating time. The solution was to attribute some opacity properties to the two different entities of the media:

- In the obstacle surfaces, we have:
    - Sudden loss of visibility (in %) at the intersection point;
    - Linear loss of visibility over distance (in %/m) in the space beyond the intersection point.
- In the global volume, we have only a unique value of linear loss of visibility over distance (in %/m).

The consideration of the volume, not as a passive space were the visibility ray travels but as an active media is the main feature here. This complements the information expressed earlier. The global volume is not only a seen space but also belongs to the Obstacle Space. The consideration of different situations in different regions of the global volume seemed to be a good model for reality. For example, visibility variations from interior and exterior spaces or from spaces with distinct lighting conditions could be modelled. Although, the time consumption of detecting what diverse regions of the global volume is the visibility ray really crossing prevented us from going further than a global loss.

—Visibility Function—

(View Point(X1,Y1,Z1), Viewed Point(X2,Y2,Z2)) = 0 to 1

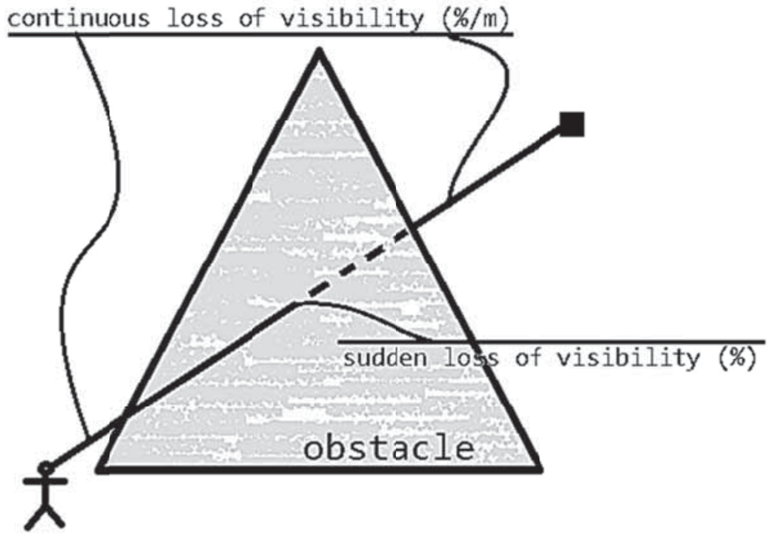

Figure 06.3
Visibility relations.

Visibility as Kernel of Other Activity Functions

The space syntax paradigm is all about visual action. All the other concepts are constructions semantically generated over it. For example, another key activity function—connectivity—is, in fact, a visual connectivity. Of course, other technologies deal with the denotational concept of connectivity in rather different approaches. For example, some traffic (management and control) technologies deal with a connectivity concept that is not visual but much more alike to the hydrodynamic studies of networks of water pipes. Having in mind the human impossibility to create a unique and complete representation of reality, we have to create bounded theories. Each conceptual model deals with reality, but it treats the reality with some human purpose in mind. We make these considerations because at some point we had considered enlarging the scope of the software to other activities. However, for the moment, we are strictly tied to the visual space syntax paradigm.

Operational Model

Conceptual technologies have to be translated in material procedures. We have to put everything in some amount of work performed by men and machines. Thus, a technological project is always an equilibrium exercise between the accuracy of the solution and the technical means and material resources implied, including, not the least important of them,—time.

Topological Representation

The first decision concerns topological representation. The current three topological representations of space syntax are metric spaces, axial lines, and graphs, organized in descending order of quantity of information and upward degree of abstraction. Each one has its uses, pros, and cons. Graphs are purely topological, not metric spaces, so they can be exempt from 3D. There are no 2D or 3D graphs in this context. Axial lines can be improved by adding elevation property, but there are already software applications doing the job. It is with metric space that the merits of 3D shine. DepthSpace3D is implementing only this one representation. Of course, it would be nice to use the amount of data input of the A&US–studied problem to automatically create axial line and graph representations. This is not out of question in late developments of DepthSpace3D. That implies a new revision of concepts.

What is an axial line in 3D? What is a node in a graph? They will be some products of division and aggregation operations in the conceptual spaces, but a profound research has to be made.

Continuum or Discrete

In a first approach, the Visibility Function has a continuous domain (and a real number between 0 and 1 counter-domain). View, Viewed, and Obstacle Spaces are continuous Cartesian spaces or sets of them. Dealing with the problem analytically would be much better then by numerical means. Analytical methods are more easily accurate and much cheaper in memory, time, and other material resources. However, mathematicians know very well that many analytical solutions are very hard to find. It is easy to see that a full, continuous analytical solution for the calculation of that Visibility Function will have very hard work finding a mathematical theory that deals with the problem, maintaining continuity. The solution we endeavored was the representation of the Visibility Function as a (huge for real cases) set of partial Visibility Functions, each of them continuous, applied (with a domain) to each independent (that is to say, separated by the frontier where continuity broke) portion of space. It must be said that this was only an academic amusement. It was clear from the beginning that the solution had to be not analytical, but numerical, through discretization of the concerned spaces. Even in easier 2D, this is the common type of solutions. In this way, visibility analysis becomes visibility graph analysis.

Discretizing the Spaces

The View Space was discretized in a set of points. Each point (X, Y, and Z) represents a possible amount of space where people can stay. Although, tendentiously, all the points will represent the same amount of space, they can have a different volume. In addition, as there can be some differences in the density of viewing agents per volume, there is a weight attribute.

—X, Y, Z, Volume, Weight, Defines a View Point—

The Obstacle Space is discretized in a set of triangles. The triangle was used for reasons that are obvious to those who have to implement space algebras and analytical geometry in computer calculations and graphics. We will spare the reader to the details. We will only say that three points define a flat surface.

Everybody knows that a four-legged chair is a carpentry joke. God created the world prone to syntactically triangular geometries. Nevertheless, Man insists in making square and orthogonal buildings. Therefore, the obvious triangular choice is not without fault. You will notice the difficulties in the graphic presentation of the results of DepthSpace3D calculations, with sharp and imperfect transitions. It is possible to create another level of static semantic in the model, to translate from a triangular calculation to and from a quadrangular user interface. Maybe, after many requests…

—The Obstacle Triangle is defined by—

(P1(X1, Y1, Z1), P2(X2, Y2, Z2), P3(X3, Y3, Z3))

The Viewed Space-Global Volume is discretized in a set of points. Although data representation does not impose any other restriction, the user interface guides to an equal amount of space for each point. Global space is cut in axial (X, Y, and Z) slices of equal thickness in each axis. Although, the thickness can be different from axis to axis.

—A Global Volume Viewed Point is defined by—

(X, Y, Z, Volume)

The Viewed Space-Surfaces are discretized in a set of points. DepthSpace3D offers two possibilities, each of them with advantages and defects. One is made by dividing each triangle in little homomorphic triangles, each one with the user-demanded area. Then the center points of those little triangles are used. The other option is rather slow to explain.

—A Surface Viewed Point is defined by—

(X, Y, Z, Area)

The Visibility Function

Finally, the Visibility Function is represented by a set that is the Cartesian product of all the View Points by all the Viewed Points. Each View Point x Viewed Point relation of this Cartesian product has a real number value—Visibility—and is defined by (View Point, Viewed Point, and Visibility).

Other View Point x Viewed Point Attributes

Each View Point x Viewed Point relation may have many space syntax attributes, other than Visibility. All the applicable space syntax quantities, such as 2nd moment or skewness may apply. However, they are derived quantities. They will be better discussed later. However, there are two other quantities of the relation View Point x Viewed Point that DepthSpace3D treats as primitives. The first is Distance (between View Point and Viewed Point) and the other is Depth.

Depth

Depth is a derived concept from the primitive Visibility. Nevertheless, as it would be difficult to work with it in the same way as the other derived concepts, DepthSpace3D calculates and offers Depth as a primitive to the users. There is a difference between 2D analysis and the DepthSpace3D concept of Depth, due to the distinction of View Space from Viewed Space. The minimum number of straight lines to unite two points is no longer applicable. Depth is now a relation between a View Point and a Viewed Point and is the minimum number of straight lines a viewer in the View Point has to perform to arrive to a new View Point where he can see the Viewed Point.

Other Operational Features

Some other operational features are worth being related.

Paths

The concept of Path, already present in 2D analysis, is maintained in DepthSpace3D. Paths constitute sets of View Points that have this same attribute. It is intended to model variegated situations in the Viewing.

It is possible to make a path with a tourist route, a path for normal use, a path for employees, a path for customers, a path for housing, a path for offices, a path for surveillance cameras, for example, and so on. Each path has its density that represents the amount of viewing people. This density multiplied by the volume of each View Point gives the weight of each View Point. This organization allows the study of different scenarios of human distribution. DepthSpace3D allows the user to define a tree network of main paths with their sub-paths.

Properties/Attributes

It is possible to attribute special properties to the Viewed Points—either Surfaces or Global Values. This enables DepthSpace3D to perform statistical treatment of the Visibility Function aggregating results by those values. The possibilities are completely open to the user. For example, he can attribute functions to the points in Global Space—commercial, services, and housing, or rest, food, and cleaning, and so on. Then we may calculate space syntax quantities using those aggregating properties: what is the global connectivity between the kitchens and the bathrooms?

Database

Treating a problem with information and computational technologies implies a strict formalization in the language that represents the problem. All the entities needed to formalize DepthSpace3D are stored in a database with the following structure.

Although the database design may appear very confusing, it must be noticed that more than 80% of the database concerns information needed for the user interface. In fact, the "scientific" sections of this database are very small. For the moment, this database is developed in MS-Access. However, in the future, it will also be provided in SQLServer. The great advantage of this implementation is the openness of the software. The structure of the database is provided and can be used outside the DepthSpace3D by everyone interested in other developments.

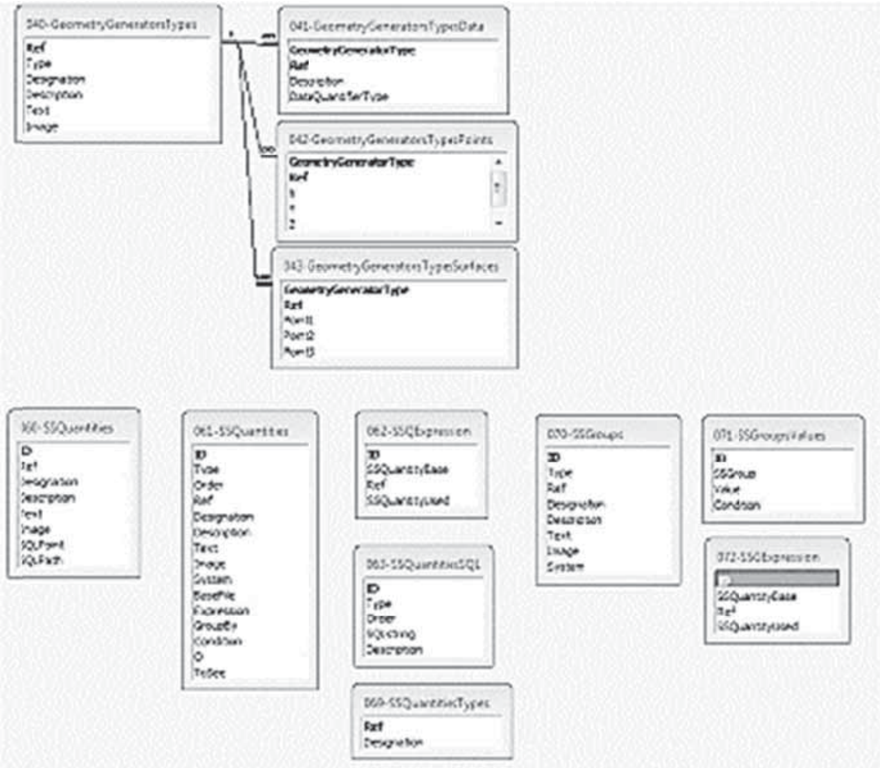

Figure 06.4
—Data for all projects—

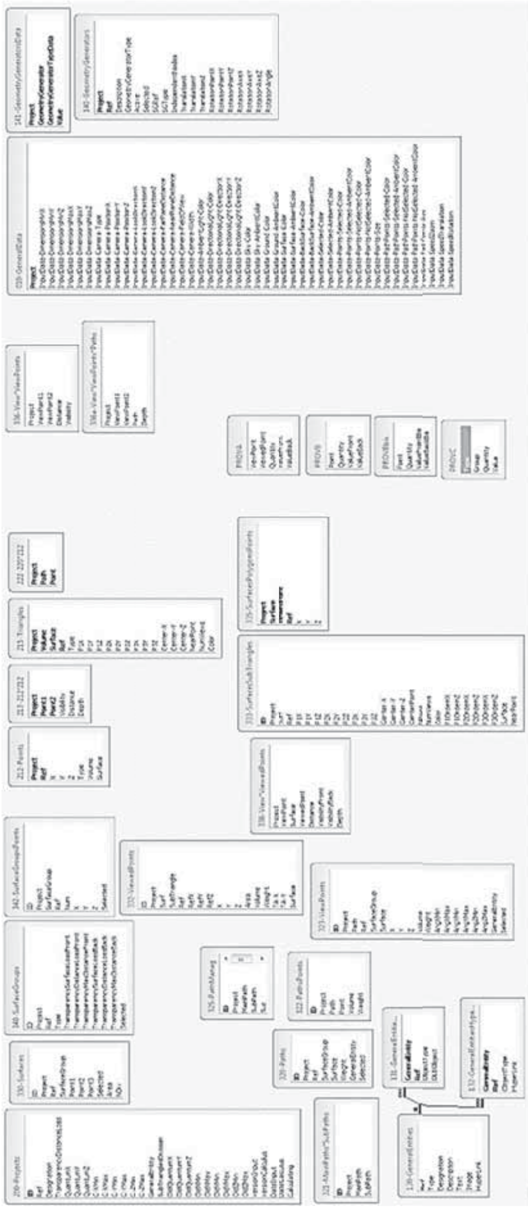

Figure 06.5
—Data for each project—

Derived Concepts

DepthSpace3D includes an editor for a generative grammar that can expand the space syntax lexicon to be used. The primitive quantities are visibility, distance, and depth. Nevertheless, it is possible to declare how to produce new quantities. This is done through SQL queries, a well-known and widespread query language for SQL databases such as MS Access and SQLServer. For example, isovista of a View Point is defined by the following SQL procedure:

```
UPDATE PROVB INNER JOIN (337-View*ViewedPoints) ON
PROVB.Point = (337-View*ViewedPoints).ViewedPoint SET
PROVB.ValueFront = (VisibilityFront), PROVB.ValueBack =
(VisibilityBack) WHERE ((((337-
View*ViewedPoints).ViewPoint)=#PP#));
```

Figure 06.6
SQL procedure for an isovista of a View Point.

Although the current version of the software only allows full SQL text, a version that will help an unskilled user to create standardized SQL queries in a friendly way is under preparation. In the meanwhile, the MS-Access development environment helps the user in the creation of SQL queries with a graphic interface, and no need of SQL language expertise is required. Another example, Convex Space, is a very used concept in space syntax. However, in fact, it is not a primitive concept but a derived concept. It can be constructed from the visibility information in the database. It could be defined as a set of all the Viewed Points that can all be seen by the same set of View Points. Moreover, if we only want the main convex spaces, we could eliminate the convex spaces that are subsets of other convex spaces.

User Interface

DepthSpace3D is not a full commercial quality version. Although, it has many of the qualities that characterize them. Special attention has been given to the user interface that we intended to be as user friendly as commercial applications are (Figure 06.7).

General Proceedings

The usual sequential use of DepthSpace3D is as follows:

- Input data—3D modelling of the "geography" of the reality.
    - The features of the edition process include some operations of a light CAD app.
        - Select, create, copy, delete, and change properties (especially coordinate transforms—rotation and translation) of all the elements—View Points, Surfaces, and Global Volume.
        - Geometry generators of several current geometric forms—parallelepiped, cones, and so on.
- Calculation.
- Output data—view results.
    - Results of calculation are shown with a colorful representation of any of the Space Syntax properties.
        - 3D of the Viewed Surfaces.
            - 3D of any slice of the Viewed Global Space.

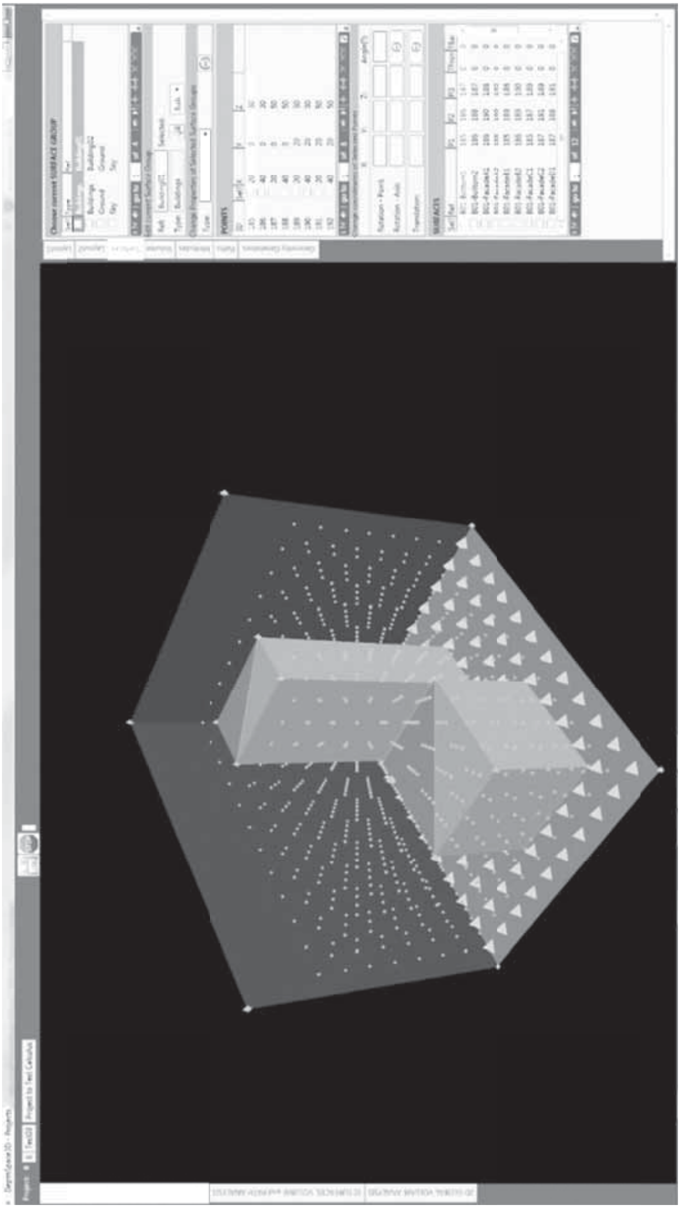

Figure 06.7
DepthSpace3D user interface.

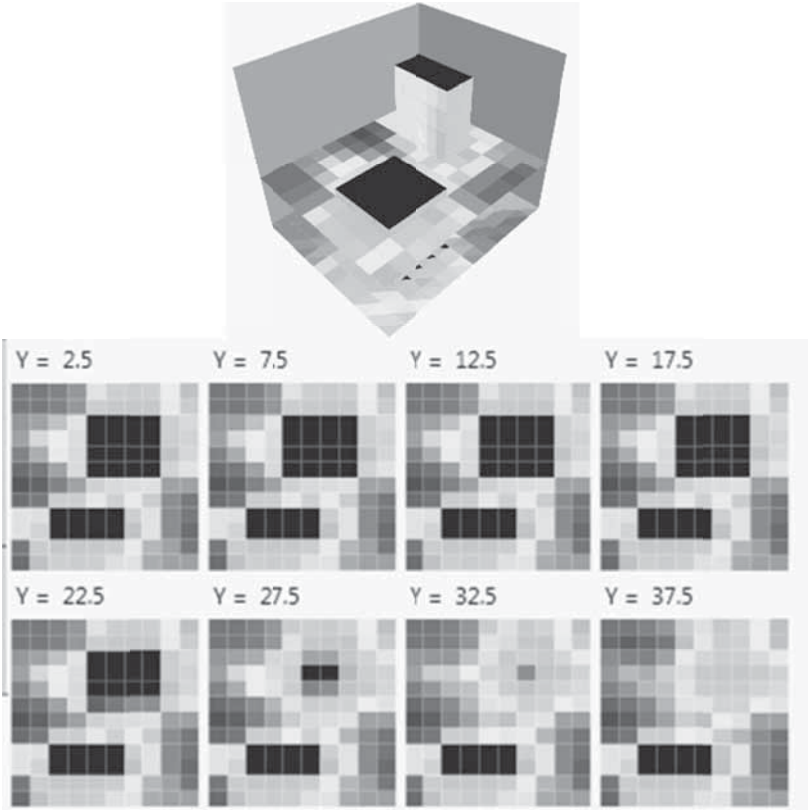

Figure 06.8
—Representation of space syntax' properties—

- 2D of all the slices of the Viewed Global Space
- 3D of the View Points

Sub-Projects

Borrowing some concepts from algebra, we could say that the current visibility analysis (VA) is an operator that does not assume the distributive property. If we perform VAs on sample A and sample B and then we perform VA over sample A+B, we will have

$$VA(A) + VA(B) <> VA(A+B)$$

This is an overwhelming fault that every user of VA is well aware of. This means that, in VA, we cannot deal with a big problem dividing it in small problems without a loss of accuracy. As there is a single and highly interrelated reality (the mother of all problems), any cut in that reality, if not carefully done, will result in rude mistakes. The bad news is that, no, we are not solving the problem. The good news is that, although it's a very humble contribution, DS3D is able to divide and sum portions of sample spaces to be analyzed, but only when they refer to input data and not analysis results.

Future Work

Future releases will be provided with several improvements, such as:

- Import/export from and to commercial CAD applications.
- Automatic calculation of convex spaces, axial lines, and graphs.
- Viewpoints with angles
- Evolutions in the graphical representation of the Global Volume Viewed Space.
- Agents
- Dynamic spaces that can take some different configurations over time.

Availability

DepthSpace3D is under continuous development. Groups in the Bartlett-UCL, the AA, and FAUL are helping in the testing of the early versions. Alpha versions of DepthSpace3D are available. A free version for academic uses will be always available from the ESAP team. Source code is also available. It was developed in MS Visual Studio development environment, spread all over the world as an environment to develop commercial apps with rich user interfaces. Currently, it is released for Windows OS but will be available for other OSs.

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CHAPTER SEVEN

A DATA MINING–BASED METHODOLOGY FOR THE MULTIDIMENSIONAL STUDY OF PUBLIC OPEN SPACES

JOÃO V. LOPES

Introduction

The identity of the public open space does not manifest itself only in its form and history. Non-discursive attributes, in Hillier's words,[1] cognitive and perceptive attributes not representable by traditional methods, as well as use, appropriation, and environmental idiosyncrasies are part of it. Only the simultaneous consideration of such a heterogeneous set of characteristics may reveal its identity, as well as unsuspected familiarities. Given human limitation to apprehend spaces or problems with more than three or four dimensions,[2] the combination of several theories and spatial and site analysis methods with data mining helps to overcome this inability. It allows the creation of new bottom-up knowledge from the very structure of the data itself and may help to promote the integration of urban morphology disciplines and design. The creation of more complex typological descriptions is essential in capturing desired qualities embedded in the urban structure, and so is its classification. We present a methodology for the analysis and classification of public open space, focusing on the formal square, which is accepted as an individualizable urban element. Collecting contributions from the disciplines of urban morphology and site analysis, it aims to synchronically and multi-dimensionally characterize and classify these urban spaces. It resorts to multivariate statistical analysis and inductive patterns search techniques in large data sets by data mining. We choose a corpus comprising a set of 126 Portuguese squares. This specific corpus (Figure 07.1) has been selected because it characterizes a significant sample in the context of Portugal mainland.[3]

The information is comprehensive and available in digital format, the representation is systematic, consistent, and updated; it offers a careful historical and architectural analysis in the perspective of the Italian school of urban morphology, and it has been a basis to other investigations. There are no spatial or formal data quantified, and that will be our first task.

Figure 07.1
Typical graphical representations of the corpus.
Example: Giraldo square, Évora, in *Squares in Portugal*.[4]

The overall research objectives are: i) the design of an original multidimensional inductive method for the characterization and classification of public open spaces, able to gather descriptive and structural approaches in a single analytical process; ii) to relate morphological features with measurable quality and performance attributes of urban spaces by data mining; and iii) to conceive an urban design approach based on concepts, workflows, and digital tools structured in such a way to take advantage of the method proposed. This chapter focuses on the first objective and continues discussing: (2.) background review; (3.) methods and tools adopted, initial assumptions, definitions, and workflow; (4.) analytical algorithms for more complex attributes' extraction; and (5.) conclusion and future work.

Background

Studies of urban morphology seldom carry out detailed analyses and classification proposals of urban environments and elements from different perspectives at various scales and complexity levels. The latest of the disciplines in this field, space syntax,[5] whose theories, models, and tools will support us greatly, has within its best-known studies and applications the urban square (notably Trafalgar Square in London).

Campos,[6] and Campos and Golka,[7] investigate the relationship between patterns of use, network configuration, and visibility by studying the penetration of axial lines, the effect of isovists and visual fields,[8] through visual graph analysis (VGA),[9] on the space of London squares. Cutini studies Tuscan historic squares (piazzas), focusing on the relationship between centrality, configuration, and visual analysis, extending space syntax measures by creating a new compound VGA index that depicts the hierarchy of convex spaces in settlements.[10]

The classic methods of urban morphologic analysis, usually limited to the analysis of single or pairs of variables to respond to human cognitive and perceptive limitations, restrict the simultaneous expression of features that give spaces their uniqueness and transform them into places.

Gil *et al.* compile the shortcomings of traditional typomorfological approaches: their time-consuming methods, restraining the number of examples and dimensions, their relative opacity, subjectivity, and dependence on the analyst's abilities and geographical/cultural contexts, questioning their reproducibility and generality.[11]

Some recent structural approaches try to escape these limitations by relating attributes and classifying examples through clustering in multivariate tri or quadrangular graphs.[12] The identified deficiencies can be handled by the use of new computational methods that allow for multidimensional analysis and typological classifications based on multivariate statistical models, exploratory data analysis (EDA), and machine learning. Most of these methods are currently included in the set of techniques associated with data mining. Within urban morphological studies, they support analyses at different scales: from the Laskari *et al.* study on urban identity through quantifiable attributes on blocks' shape at district level,[13] to street patterns in metropolitan areas.[14] Gil *et al*.,[15] in an unsupervised classification of the urban fabric of two neighborhoods of Lisbon focusing on street and block elements, mention the possible integration of these techniques in design. Chazar and Beirão point the potential of their expansion to the analysis of non-formal spatial qualities,[16] leading to a better understanding of the public open space morphology. Although multidimensional analyses of the urban void are rarer, Laskari analyses the blocks' residual void space in a neighborhood of Athens through a set of thirteen properties and by different multidimensional methods.[17] The syntactic analysis of convex spaces is being enriched by the ongoing work of Beirão *et al.*,[18] which introduces a new urban void 3D analytic method and new classification and aggregation logics of its elementary units.

Method

Methodologically, this research collects concepts and tools from the urban morphology, GIS, algorithmic design/parametric urbanism, and data mining fields. The attributes are extracted through (virtual and real) surveys, and geographical and urban models based on the digital representations of the corpus. According to scale and goal, we use analytic tools from geography (QGIS, www.qgis.org), space syntax (Depthmap, UCL), and parametric-algorithmic design (Rhino/Grasshopper, McNeel & Assoc.). Hanzel points out the advantage of the latter, over other CAD and GIS platforms, in local scale urban modelling.[19] Their associative and interactive 3D nature, rule base approach, and data integration flexibility promotes the synchronization between analysis, representation, and design. As their processes are explicit, initial criteria and assumptions can be easily updated. For multidimensional analysis, we resort to RapidMiner (RapidMiner GmbH), a popular data mining software (such as Grasshopper) based on patterns, and a visual programming interface (VPI).

Data mining, at the intersection of artificial intelligence, machine learning, statistics, and database systems, finds patterns and rules in large data sets via inductive methods. Its main objectives are prediction (classification of unknown cases and regression) and the discovery of new knowledge (finding unknown patterns in data).[20] Among the various methods implemented in data mining, we intend to start by exploring two of the most established in practice: principal component analysis (PCA) and clustering (k-means and k-medoids algorithms). The PCA analysis determines a smaller set of (artificial) variables that summarizes the original data with minimized loss of information and is capable of revealing unsuspected relationships. Clustering is an unsupervised classification process that assigns objects to groups (clusters), so that the objects of each group are more similar to one another than with the objects of other groups. It aims at discovering natural groups of objects or variables, identifying extreme and prototypical cases, and suggesting interesting hypotheses about relationships.

Analysis scales and boundaries

To adapt the nature of each recorded attribute to their characteristic spatial scale and representation, boundaries or spatial aggregation scales are defined. Despite the artificiality of their definition, given the continuum nature of the urban void and network, and the problems raised by sensitivity to frontier conditions, five operative boundary categories are proposed (Figure 07.2):

(1) Site boundary, which is determined by the 2D closed polygon formed by the extension of the facade segments and plots' limits that clearly form the space of the square. This determines factors related to shape, perimeter visibility/connectivity, and public/private permeability at the most local scale.

(2) Neighborhood boundary, which is determined by the streets bordering the adjacent blocks to the previous border within a minimum radius of 250m. It highlights the aggregation of features related to local urban indices, densities, and VGA analysis, while ensuring contextual influence.

(3) Settlement boundary, which is determined by the limit of towns (or a minimum radius of 1,5km) and provides information on centrality, intelligibility, and synergy features relating local to overall structures.

(4) Regional boundary, which is defined by political/administrative or historical/natural frontiers.

(5) National boundary, which is the most generic boundary comprising all the examples and defined by the Portuguese mainland frontier. It depicts, along with (4), socio-cultural differences at a regional and national scale.

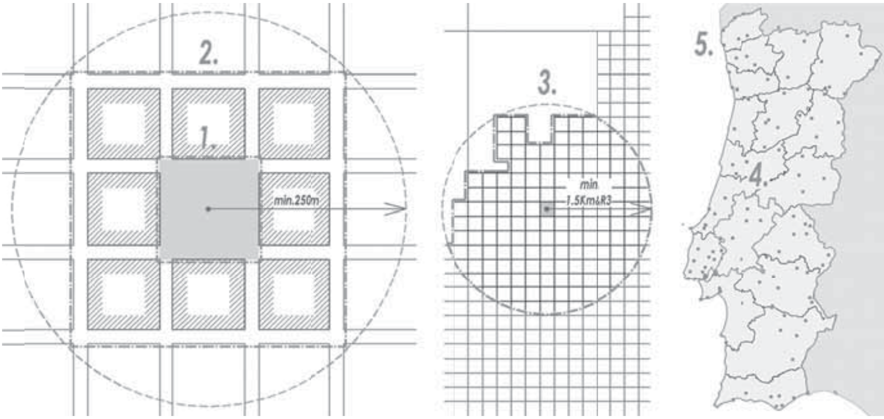

Figure 07.2
Analysis scales and boundaries: diagrammatic representations.

Spatial and formal attributes of the squares

The definition of the initial set of attributes to be quantified for each of the squares is founded on review and discussion of related work. We gather generic morphological, syntactic, and environmental descriptions, local and global features from various disciplines, as heterogeneity of attributes is essential to the proposed method. Its value lies in the ability to reveal non-obvious correlations through dimensionality reduction and visualization of big data sets.[21] The attributes were divided into eight thematic groups (Figures 07.3 and 07.4), which reflect both the diversity of approaches and scales.

I. Void shape. Attributes extracted from the two-dimensional representation of the square by its site boundary, analyzed as a polygon, to extract geometric measures, ratios, and shape factors.

II. Vertical plane and permeability. Attributes related to the three-dimensional expression of the space perimeter and the facades, both their geometry and their behavior as interface between public and private.

III. Urban indices and density. Attributes that relate the area of the square to the area of the surrounding blocks and buildings in terms of their built area and footprint. It focuses on density measurements inspired by Spacematrix theory.[22]

IV. Visibility and connectivity. Visibility properties, according to: *(i)* the distribution of connectivity along the square perimeter and the inter-visibility of the facades; *(ii)* VGA analysis limited by the neighborhood boundary, aggregating the values inside the square perimeter; and *(iii)* the visibility from the exterior of the square, through the calculation of external isovists' overlapping area and perimeter.

V. Urban system. This attribute theme focuses on the features of the squares' embedding urban system. Extraction of local and global syntactic values of the axial lines crossing the square, their lengths, and geometric relationships.

VI. Use and appropriation. Attributes that classify buildings adjacent to the square into classes, according to their uses, and register the existence of exceptional buildings and characteristic elements of the urban squares (fountains, bandstands, pillories, kiosks, etc.).

VII. Environment. This group deals with the existence of natural elements and other environmental features (e.g. visible sky area percentage, solar orientation, or the maximum topographic slope). These attributes, and the previous ones, are related to urban quality potential, which will have to be interpreted in their specific geographical contexts.

VIII. Generic labels. These are essentially attributes related to geographical factors and territorial distribution, or some sort of à priori classification (labelling), whose correlation with the data can be tested or machine learned.

As the analysis progresses, the definition of the attributes may change and be optimized. To increase the expressiveness of the data, its correlation and type of statistical aggregation shall be attested by EDA analysis and by the early modelling of the data mining algorithms.

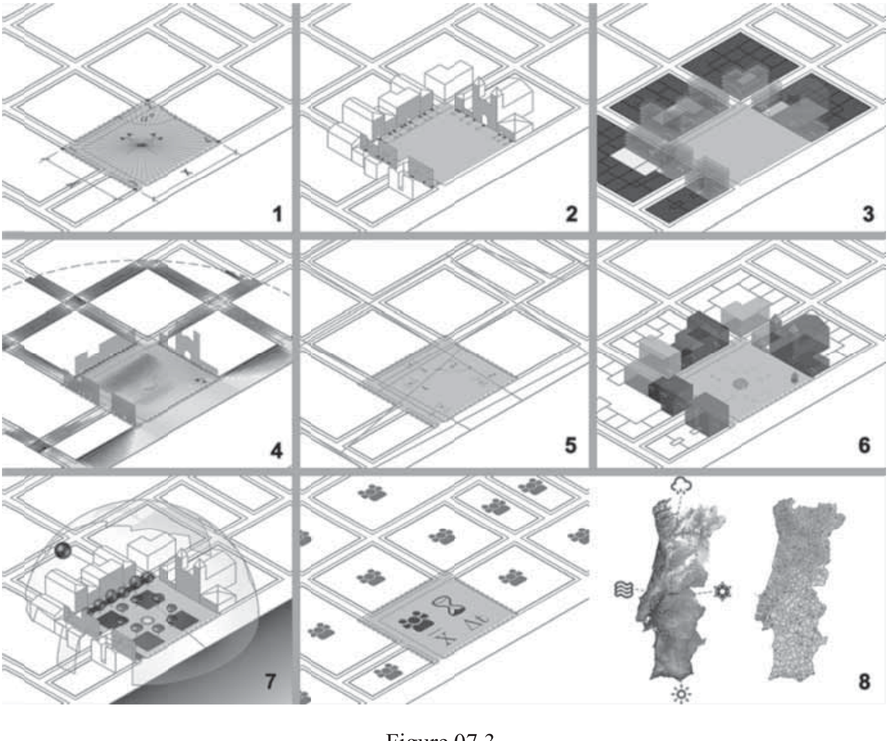

Figure 07.3
Attributes and attribute groups: diagrammatic representations.

#	Attribute	Code	Boundary	Unit	Data type	Main theory
	(1) VOID SHAPE					
1	Area	Vs A	Site	m2	Real	Shape
2	Area/perimeter ratio	Vs RP	Site	_	Real	Shape factor
3	Nr of perimeter vertices	Vs NV	Site	_	Integer	Shape
4	Nr of internal islands	Vs NI	Site	_	Integer	Shape
5	Length of the longest side (angular deviation > 15°)	Vs LL	Site	m	Real	Shape
6	Aspect ratio (elongation)	Vs AR	Site	_	Real	Shape factor
7	Circularity ratio (isoperimetric quotient) (spikiness)	Vs CI	Site	_	Real	Shape factor
8	Entropy (symmetry)	Vs EN	Site	_	Real	Shape factor/GIS
9	Rectangularity ratio (rectangularity)	Vs RR	Site	_	Real	Shape factor
10	Perimeter fractal dimension-Hausdorff dim. (roughness)	Vs FD	Site	_	Real	Shape factor
	(2) VERTICAL PLANE, AND PERMEABILITY					
11	Perimeter/block frontage ratio	Vp RB	Site	_	Real	Urban Morphology
12	Facade area	Vp FA	Site	m2	Real	Urban Morphology
13	Maximum height of the facades	Vp MAH	Site	m	Real	Urban Morphology
14	Mode of the heights of the facades	Vp MOH	Site	m	Real	Urban Morphology
15	Entropy of the heights of the facades	Vp EN	Site	_	Real	Shape factor
16	Opening density (opening nr/m frontage)	Vp OD	Site	_	Real	Space Syntax
	(3) URBAN RATIOS AND DENSITY					
17	Nr of adjacent blocks (= nr of adjacent streets)	De NBL	Site	_	Integer	Urban Morphology
18	Nr of adjacent plots	De NP	Site	_	Integer	Urban Morphology
19	Nr of adjacent buildings	De NBU	Site	_	Integer	Urban Morphology
20	Urban square area/adjacent blocks area ratio	De SBL	Neighbour.	_	Real	Spacematrix
21	Urban square area/adjacent building footprint area ratio	De SF	Neighbour.	_	Real	Spacematrix
22	Urban square area/adjacent built area ratio	De SBU	Neighbour.	_	Real	Spacematrix
	(4) VISIBILITY AND CONECTIVITY					
23	Min nr of convex spaces	Vc MC	Site	_	Integer	Space Syntax
24	Perimeter mean connectivity value (mcv)	Vc MCV	Site	_	Real	Space Syntax
25	Vertical stand. deviation perimeter connectivity (v-value)	Vc VV	Site	_	Real	Space Syntax
26	Horizontal stand. deviation perimeter connectivity (h-value)	Vc HV	Site	_	Real	Space Syntax
27	Mean horizontal value (mhv)	Vc MHV	Site	_	Real	Space Syntax
28	Area overlapping isovists from the street (visual exposure)	Vc VS	Neighbour.	_	Real	Isovist
29	Urban square area/major isovist (360°) area ratio	Vc PI	Neighbour.	_	Real	Isovist
30	Area of the visual integration core (visual integration >90%)	Vc CO	Neighbour.	_	Real	Space Syntax VGA
31	Mean visual connectivity (less prone to edge effect)	Vc COM	Neighbour.		Real	Space Syntax VGA
32	Mean visual clustering coefficient (less prone to edge effect)	Vc COE	Neighbour.		Real	Space Syntax VGA
	(5) URBAN SYSTEM					
33	Mean width of confluent streets	Us SW	Neighbour.	m	Real	Urban Morph./Design
34	Sum of the confluent axial lines length	Us AL	Settlement	m	Real	Space Syntax
35	Mean angle between confluent axial lines	Us ANL	Settlement	Degree	Real	Space Syntax
36	Maximum confluent axial lines global integration	Us GI	Settlement	_	Real	Space Syntax
37	Maximum confluent axial lines local integration (radius3)	Us GI3	Settlement		Real	Space Syntax
38	Maximum confluent axial lines global choice	Us GC	Settlement	_	Real	Space Syntax
39	Maximum confluent axial lines local choice (radius3)	Us GC3	Settlement		Real	Space Syntax
40	Mean intelligibility (local connectivity/global integration)	Us IN	Settlement	_	Real	Space Syntax
41	Mean synergy (local (r3) integration/global integration)	Us SY	Settlement	_	Real	Space Syntax
	(6) USE AND APPROPRIATION					
42	Adjacent building use (Church/historic building; Public building/Urban equipment; Comerce/Services; Residential)	Uu BU	Neighbour.	–	Polynom.	Land use
43	Urban elements (Bandstand; Pillory; Benches; Kiosk; Urban art; Fountain)	Uu EL	Site	_	Polynom.	Urban design/Usage
	(7) ENVIRONMENT					
44	Natural elements (Water; Green space; Trees)	En NE	Site	_	Polynom.	Site analysis/Landscape
45	Mean sky component (sky hemisphere visiblity %)	En SK	Site	%	Real	Site analysis/Solar
46	Area in constant shadow	En SH	Site	_	Real	Site analysis/Solar
47	Global solar orientation (wheghted segment contribution)	En SO	Site	_	Real	Site analysis/Solar
48	Maximum topographic slope	En SL	Site	%	Real	Site analysis/Landscape
	(8) GENERIC LABELS					
49	Toponymic type (square, churchyard, circus, etc)	Ge TO	National	_	Polynom.	Urban Morphology
50	Geografic/climatological region	Ge GE	Regional	_	Polynom.	Geography
51	Latitude (north/south differentiation)	Ge LA	National	Degree	Real	Geography
52	Longitude (coast/inland differentiation in Portugal)	Ge LO	National	Degree	Real	Geography
53	Site elevation	Ge EL	Regional	m	Real	Geography
54	Date (first historical reference: century)	Ge DA	_	_	Date	Urban Morph./History
55	Population density at square civil parishes' level	Ge PD	Neighbour.	_	Real	Demography

Figure 07.4
Table of attributes metadata.

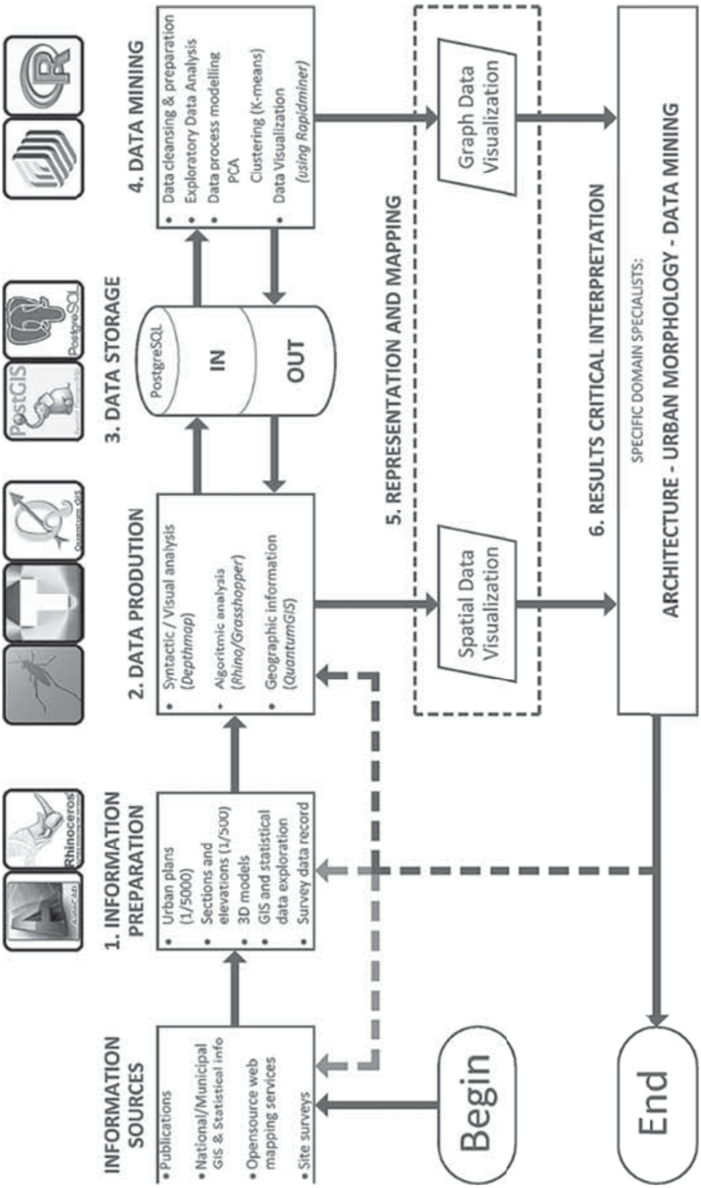

Figure 07.5
Workflow diagram and tools.

Workflow

The proposed workflow (Figure 07.5) includes the gathering and preparation of information, building the models and analytical algorithms, the attributes extraction, tables' construction, and the data storage in a PostgreSQL relational database, a scalable central repertoire aiming at streamlining the workflow. The data mining and visualization of statistical information will be made with RapidMiner, and their spatial mapping in Rhino/Grasshopper and QGIS. Data visualization will be essential to the critical interpretation by field experts from which may result the redefinition of the initial assumptions and the process itself.

Analytical Algorithms

Some of the squares' simple attributes (lengths, areas, counts) are extracted directly from the 2D and 3D models without further processing, and composed attributes (ratios, densities, shape factors) are calculated within the database. We briefly describe some of the developed algorithms requiring more complex and/or specific modelling (Figure 07.6):

- Fractal dimension (Hausdorff dimension by a coast of Britain-like process) (Figure 07.6[1])—the Hausdorff dimension (or covering dimension) is one of the mathematical definitions for fractal dimension. This is a statistical index of the roughness of a pattern and its definition is based on the principle of the change in detail with scaling. It corresponds to the limit of the slope for the regression line of a log *vs* log graph of a function size vs scale.[23] In our model, the pattern is the square perimeter, size is the number of equal segments (rulers) forming a polyline whose vertices slide on the perimeter line, and scale is the length of these rulers. This last factor has to be carefully considered, as detail is finite in the graphical representations. The approximation to the Hausdorff dimension is an iterative process in which rulers double their length in each iteration, on a scale between 0.5m and 64.0m considered appropriate to the squares' plan scale (1:1000). This is done in Grasshopper, including the calculation of the regression line and its slope: the estimated fractal dimension. This method is implemented alternatively to the box-counting method as it is computationally less expensive and insensitive to the shape spatial orientation. Still, in cases of extreme convulsion it is sensitive to the direction of the rulers. In general, for non-mathematic fractals the Hausdorff and box-counting dimensions coincide.[24]

- Perimeter Connectivity (Figure 07.6[2])—based on work by Psarra and Grajewski,[25] and Laskari *et al.*,[26] we implemented, in Grasshopper, an algorithm that allows the characterization of shapes by analyzing the connectivity of their perimeters. A set of measures are defined that allow the description of shapes as patterns of stability and differentiation, rhythm and repetition, and their understanding beyond the conventional characterization of its geometric order, quoting Psarra and Grajewski.

- The measures, based on visibility values between segments discretizing the shape perimeter, as plotted in a graph, are: total mean connectivity value (mcv); vertical standard deviation (v-value), the standard deviation from mcv; horizontal standard deviation (h-value), the standard deviation of the distance between subsequent points of mcv value. To these measures Laskari adds mean horizontal value (mhv), the average value of that distance. Though these measures are concerned with shape description, we intend to extend the use of this model to assess the intervisibility between the space defining facades. A high degree of correlation with some squares' shape factors is expected. The models created have a typical resolution of 1.5m and calculations are made integrally in the Grasshopper.

- Shape diameters, radii, and diagonals (Figure 07.6[3])—the outlined algorithm is capable of finding the major segment inscribed within the perimeter of the square (major diameter), and the major and minor ones perpendicular to it (minor diameters), as well as the lowest absolute diagonal originating from a vertex. It deals with convex and concave spaces and is sensitive to the existence of islands. Contrary to axial lines of space syntax and the concept of the diagonal of a polygon in discrete geometry,[27] this model allows the diagonals to graze the sides of the polygon. The algorithm also calculates the longest axis, passing through the centroid of the square, and its perpendicular, as well the radii centroid-vertices, and variable radial sampling from a selected point. These values allow the determination of attributes related to shape factors and moments whose calculations are mainly taken from the fields of GIS and image analysis.

- Internal and external isovists. Isovist fields (Figure 07.6[4])—strictly geometrical 2D isovists (without radial sampling) are created. Distinction between isovist polygon segments representing obstacles and occlusion lines is made, and the calculation of their geometric based measures, such as occlusion and drift,[28] can be rigorously made.

- The use of Grasshopper allows an accurate and interactive control of isovists location, resolution, and extension. Isovist fields can be created step-by-step for points in a grid, using the software-animated sliders and the data-recording component, illustrating the possibility of performing a sample for each-loop without resorting to advanced scripting. However, it is computationally expensive and not presented as a substitute for isovists by radial sampling or their calculation by specialized programs like Depthmap or Syntax2D (University of Michigan).

- Facades, building heights, solar orientation (Figure 07.6[5])—The area of the facades bounding the space is extracted from the existing conventional 3D CAD models of the corpus through automatic selection of their surfaces, which are unfolded for the purpose of visualization and mapping. The façade's height is characterized by its maximum, mode, and entropy values of its distribution, respectively accounting for the presence of landmarks, a predominant height, and its complexity. An attribute characterizing solar orientation is given by the weighted mean value of orientation (gradient from south=1 to north=0) for the square boundary segments, where the normalized segment lengths are the weights. Values closer to 1 indicate predominantly good solar orientation for the typical latitudes of Portugal, expressed as a potential since it considers the entire perimeter even if not built.

- Sky factor and 3D solid isovists (Figure 07.6[6])—this algorithm calculates the percentage of the visible area of the sky, from a point at eye level, without discretizing the sky vault. The process entails the creation of 3D solid isovists, by the extrusion of the visible facades´ surfaces to a vantage point, and their subtraction from a hemispherical surface representing the sky. The measures are expressed in percentage of the area of the initial hemisphere that represents an unobstructed horizon.

Intercepting the resulting surface with another one representing the solar movement for a given period and the local latitude, insolation can be approximately calculated. This algorithm records the average percentage of the squares sky's visible area and the area permanently in shadow, using a grid of points (sensors) spaced 1.5m. The calculation is done systematically for each of the points as described above in the construction of isovists. Other indicators can be drawn from this model relating properties of the 3D isovists or the sky map shape, such as the Gibsonian-inspired spherical metrics for the urban open space created by Teller,[29] and exemplified by that author for a set of European historical squares.

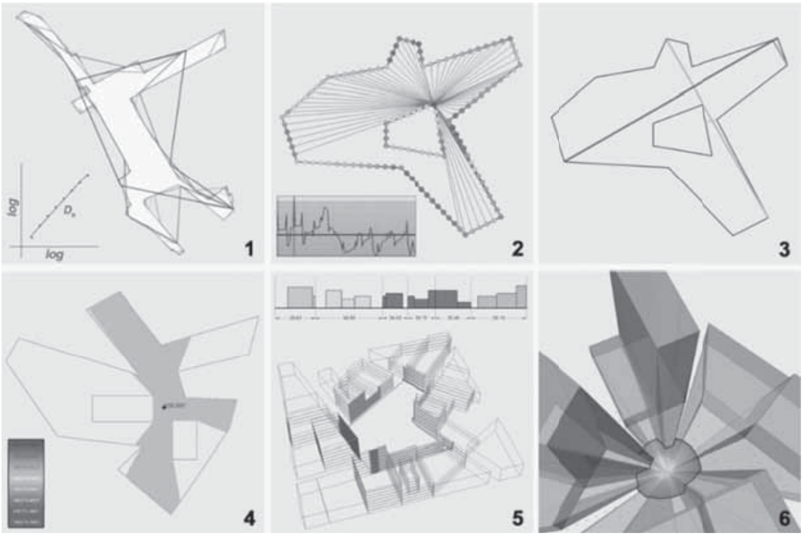

Figure 07.6(1;2;3;4;5;6).
Analytical algorithms.

Other Grasshopper definitions were devised, dealing with the creation and maintenance of PostgreSQL databases from inside Grasshopper's modelling environment, using Nathan Miller's Slingshot! component. This allows the interoperability between CAD, GIS, and data mining platforms, without resorting to intermediate file formats like shapefiles. Spatial analysis software Depthmap could only be indirectly integrated in this database workflow by parsing csv data files. Using this method, and by means of string manipulation, a Grasshopper definition allows Depthmap's axial and VGA analyses reconstruction, and data and geometry simultaneous manipulation, within the algorithmic/parametric environment.

Discussion and Future Work

We have presented a scheme for the construction of a multidimensional method specifically designed for uniquely identifying and classifying public open spaces, through the expressiveness of the data itself, and having the formal urban square at its starting point. This method entails:

- A comprehensive set of perspectives and scales of analysis.
- Using the entire spectrum of spatial dimensions.
- The synthesis of physical, spatial, and immaterial attributes in a single descriptive vector.
- The determination of the correlations between attributes and the minimum individualizing attribute set (correlation analysis; dimensionality reduction).
- The bottom-up classification of the examples by natural clustering of the data.

Despite the research project being in an early stage, there is confidence in the validity of the approach, as some general points seem clear:

- Human limitations in handling, visualizing, and discovering patterns in multiple dimensional data sets is greatly assisted, or only possible, by data mining.
- The potential of data mining in urban morphology and design is mostly unexplored.
- Multidimensional analysis in urban morphology research is recent but its advantages are well documented.
- Heterogeneous knowledge can be associated and used to classify public open space from simultaneous perspectives, and correlate it with quality attributes.

Problems encountered relate to limitations in the cartographic sources, the difficulty in completing information for some remote settlements, and the poor scalability of the algorithms created. These are intended as learning and mock-up tools for testing models that would have to be implemented through high performance programming languages like Python or C.

In future work, the potential of the method presented points in four directions:

- First, to extend the example set to other types of contemporary public open spaces that challenge the formal concept of urban square.
- Second, to deepen the potential of data mining in urban analysis, exploring other dimensionality reduction and learning (supervised and unsupervised) techniques.
- Third, to ascertain the receptivity of data mining in the urban morphology community, submitting the results to criticism.
- And fourth, probably the most significant assignment, to correlate spatial and formal attributes with urban quality or real performance measures through data mining techniques to explore the combination of this analytical method with generative design processes.

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CHAPTER EIGHT

CONSEQUENCES OF ARCHITECTURAL FORM ON SOCIAL INTERACTION: FUNCTION AS A BASIS FOR HOUSING STUDIES THROUGH SYNTACTIC ANALYSIS

CATARINA RUIVO

Introduction

While the goal of the background study was to develop and to apply methodologies of formal and quantitative analysis to the complex context of collective housing in the 20th century in Porto, in its political and social implications, the focus of this chapter is the development of a methodology of analysis. Particularities in the case studies will be addressed as a means for a better understanding of the potentialities of the method.

This chapter will initially establish the relevance and importance of the development of a methodology of formal analysis that, based on already established theoretical ground, uses architectural function as a basis for understanding social relations. It will then expose how such a methodology can work, and what its main limits and potentialities are.

Based on the premise that architecture is a main organizer of human activity, and so of the relationships established between social groups and individuals, the methodology for analysis of architectural form, here developed, is based on the quantification of the relations established between the functions inherent to dwelling. These are of mobility, visibility, and density, and it is through these that the concepts of privacy and segregation, as well as others essential for their development, are then defined within this study through which conclusions about the case study can be reached.

The case study, consisting of thirteen collective housing experiences built in Porto throughout the 20th century, though not thoroughly explored in this chapter, will be introduced so that the methodology and its potentialities can be better understood in the confrontation with reality. The chosen case studies were built between 1933 and the present day. Each case was analyzed and then in relation to the whole set so that it is possible to draw conclusions about the relevance of the methodology of analysis, as about the way housing evolved since 1933, recognizing patterns and spotting exceptions that can be related with its historical, aesthetic, and ideological contexts. The analysis of the case study was aimed at finding answers about the adaption of the collective housing models to capitalist society throughout the 20th and early 21st centuries, and to provide a material basis to the parallel development of a methodology of analysis.

A Methodology for Formal Analysis

Human Activity and Architectural Function

> "*It seems likely that in the future, studies of houses and homes will no longer be satisfied with identifying similarities in the spatial patterning of a set of houses in a particular region or cultural context. Increasingly, analysis will seek to pinpoint the typical ways in which different room functions and domestic activities are configured in people's homes, the importance of furniture and object arrays in providing the scenery and props for social encounter and interaction, how domestic space and its fixtures and fittings relate to explicit and tacit household practices, inter-personal behaviors, domestic habits and routines, the postures and gestures which people make in haptic space and even the language and concepts which people use when talking about what their homes mean to them. Increasingly, a configurational approach will reach out to related disciplines such as sociology, anthropology and psychology in addressing the social and personal interpretation of domestic space.*"[1]

The study of space syntax theory,[2] as well as other theories and methodologies of quantitative analysis of the built environment, was essential for the development of this research. They provided the theoretical basis and practical instruments fundamental for the development of an experimental methodology of analysis, capable of being applied to the case studies and finding answers for the questions asked. However, it strays away from them as it focuses on a concept that seems less developed in the area; that recognizing that determined spaces are to an extent related to determined functions, and that these are fundamentally social.

Defining architecture as something that is in the first place the spatial organization of social relations, the functions inherent to build spaces gain particular relevance. These are what, structuring the spatial relations established between them, allow for the architectural organization of social relations between groups and individuals.

Where space syntax emerges from the analysis of the relation between different points in a bigger system, the functions of architecture are used here as the basis of a spatial system and the developed methodology is not capable of integrating various aspects of space syntax that are thought extremely valid and interesting. It's a flagrant example of this that, at this point, the concepts of axial lines and convex spaces, as a method for studying and understanding the spatial configurations in their different components and as a methodological approach to the way an observer understands convex spatial systems, haven't been adapted to the developed methodology. Axial lines and convex spaces allow for the distinction of the parts within a spatial system as the observer understands them. Instead, the methodology of analysis developed here aims at the division of space in areas of effective use, where the functions of dwelling take place. For this reason, transition spaces as streets and corridors, although taken into consideration, are not analyzed in themselves. There would also be no interest in splitting the same function into two different parts as would be inevitable in an analysis based in axial and convex maps.

According to Rapoport's house-settlement theory,[3] the built environment is divided into areas-functions, which establish different degrees of relation between them. Area-function is the set formed by the dialectic of a determined space and the activity to which it is destined, and which commonly takes place inside it. The house cannot be seen as something separated from the city, as their form changes whether certain activities take place in one or the other. Searching for relationships only inside the house would be to ignore its intrinsic relationship with the other scales of dwelling.

As dwelling does not end inside the limits of its walls, no functions are defined as inherent to one scale of dwelling. Instead, the relationship between the form of the house and that of the neighborhood, for example, are understood based on the functions present within each scale. An apartment without a bathroom does not imply people do not need to use one, but that they have to search other places for this function, probably outside the house.

The functions used in the analysis of the case studies are those that were found consistently throughout the development of the methodology, and they are not supposed to be universal or define one meaning of dwelling that is transversal to any other context than that of collective housing of the 20th century in Porto.

The case studies were chosen with the objective of representing the different initiatives and types of housing in this context. They are to be broad both spatially and regarding social classes, and paradigmatic from a certain aesthetic and ideological movement.

Within the house-settlement theory, they are analyzed at four levels: the apartment as a spatial system in itself and in relation with an outside scale, the building; the building as a spatial system in itself and in relation with an outside scale, the neighborhood; the neighborhood as a spatial system in itself and in relation with an outside scale, the close urban space; the close urban space as the public space that, while not a part of the neighborhood, is in direct contact with it—it is the exterior element to the spatial system, which includes the neighborhood, the building, and the apartment.

In each scale, the functions that can be verified in that case study were analyzed, being that the nonexistence of a certain function of dwelling within a certain scale means a non-relationship between it and all the others. The other functions are put in relation with each other so that tables can be created where both the relationship between each function with each one of the others and the relationship between one function and the entirety of the system is understood. The relationships between areas-functions can be of different kinds.

Relationships between Functions

—Relationships of Mobility—

Similarly, to what happens in space syntax theory, the relations of mobility within a system are essential for the present work. More than proximity or other geometric relations, is the permeability of a determined space that puts it in relation with the others. Only the existence of permeability allows for the direct interaction between individuals belonging to a certain area-function and those exterior to it.

Mobility is represented through a tree graph, where each white circle represents an area-function and each grey circle spaces of transition or distribution between them. It is taken into account that not all forms of transition between spaces result in the same levels of interaction—two spaces separated by a door are more directly accessible than two spaces separated by a staircase—and these different forms are considered differently in the calculation of relationships of mobility. However, without sociological or behavioral data, these measurements are necessarily arbitrary, and the methodology of analysis must be developed in a way so that these values can be altered to better adapt new knowledge.

	BFE1	BFD1
BFE1	10	4
BFD1	4	10

Figure 08.1
Example of relationships of mobility.

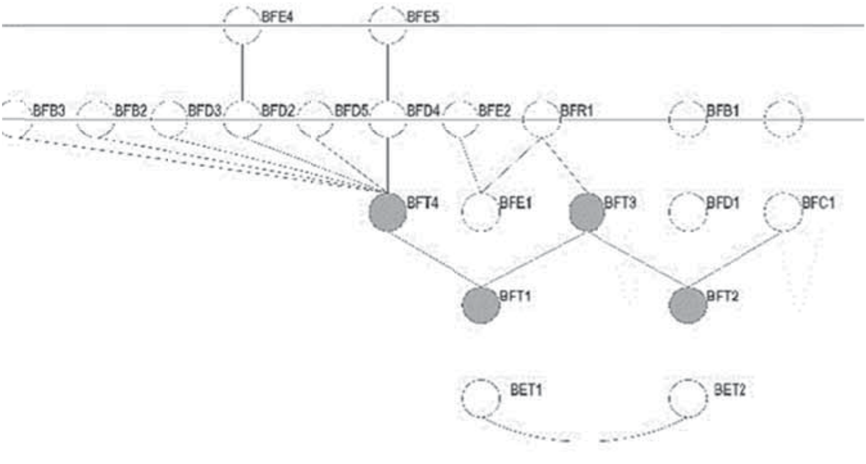

Figure 08.2
Example of a mobility graph.

Figure 08.1 represents relationships of mobility. It adopts values from zero to ten, ten being the highest relation possible between two uses, and meaning functions associated to the same space, or being the relationship of a function with itself. At the apartment and building scales, for each step the following are subtracted: three for a staircase/elevator; two for a door; one for any other type of transition, as a change of paving or height.

At the neighborhood scale, for each step the following are subtracted: three for a street that must be crossed; two for a door or relevant extension of route; one for any other type of transition. At this scale, the relationship of an area-function with the outside space, building, or apartment is calculated through the average of accessibility to the different buildings or apartments, as it is the approximate value of one area-function with all the buildings and apartments that is searched.

The relationship of one area-function with the exterior, the near city, is calculated from the nearest entrance, even if there are different arriving points, as it is the highest relationship possible, which is searched. Since relationships of mobility are always reciprocal—a door exists on both sides of it—the vertical and horizontal readings of the mobility table have the same meaning and the table is diagonally symmetric.

The average of the resulting values of one function with the others results in a value of connectivity (c)—how accessible it is in relation to all the others within the system.

—Visual Relations—

How much spaces allow individuals to see of or be seen by others has a direct influence both in the way they relate to one another and on their values of privacy and segregation. Visual relations depend on how much a determined area-function is seen by or sees of another. The percentage that an area-function A sees of the totality of an area-function B is calculated by drawing the visible amount of B from the geometric center of A on the plan. Even though this does not represent everything that can be seen from a determined space, it establishes an average of how much can be seen when inside it. It was considered using the point where the inherent function to a determined space would usually happen—say a chair for "studying" or a bed for "sleeping"—and defines what would be visible from them. However, due to the unpredictability and easy alteration of the way a space is used this seemed impracticable.

	BFE1	BFR1
FE1	10	10
BFR1	9	10

Figure 08.3
Example of relationships of visibility.

A visibility map[4] is drawn with resource to the software DepthMapX, and then the table of visual relations is constructed. It adopts values from zero to ten, zero being the nonexistence of a relationship between an area-function A and an area-function B—A can't see B—and 10 being the highest possible relationship, usually between functions taking place in the same space—when A sees 100% of B. Unlike what happens in relations of mobility, a horizontal reading of the table offers different information from a vertical one. The horizontal reading shows how much each horizontal function sees each vertical function. The average of these values results in a value of visual control (cv), the average of how much each function sees of all the others. The vertical reading shows how much each horizontal function is seen by each vertical function. The average of the vertical values results on a value of exposition (e), how much a function is seen by all the others.

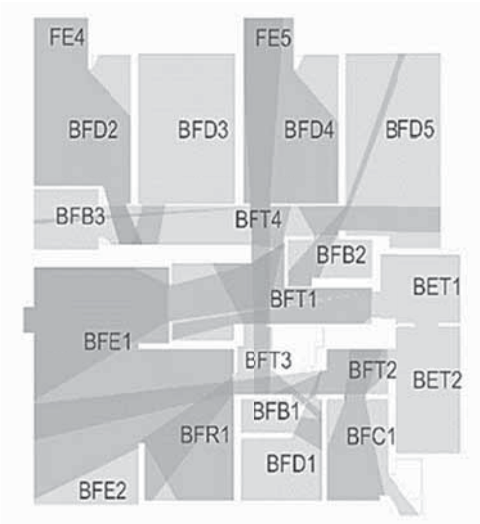

Figure 08.4
Example of a visibility map.

Even though this method functions when trying to determine the visual relations that different spaces establish between themselves, it cannot be used globally to measure all the sorts of visual relations that take place inside the case studies. When analyzing the neighborhood, there are always moments where it would be relevant to understand the visual relations between spaces and built objects—buildings that belong to the system and that relate to the exterior space through their facades instead of to its interior space. It is the case for housing buildings and different public buildings like schools and churches, which, relatively closed within themselves, can have a relevant visual presence in the system to which they belong. They differ from exterior commercial galleries and stores opening directly to the outside since their interior spaces are directly exposed to the public space, but do not always form independent buildings. Without having access to a 3D software for analysis of the built environment, the relationship between exterior areas-functions and interior areas-functions at the neighborhood scale was made through the percentage of seen façade as it could be calculated in the plan. As it is impossible to see the entirety of the façade of any given building, seeing half of the façade was considered the highest possible visual relationship with it. Even though this is not necessarily correct, as it is possible, for example, to see two thirds of the façade of a triangular building, the simplification was considered enough to accomplish the desired approximation. Therefore, 10, which would usually mean 100% of seen area, translates to only 50%, so that the relationships between two spaces and the relationships between a space and an object do not result in misleadingly different values. The inverse relationship, object-space, is not relevant here. In the field of collective housing, the visual relationship of, for example, a school's interior to the exterior public space is not of immediate interest, and it would not be operational to attempt to calculate it within this particular study. Instead of the interior space, the relationship is established with the main entrance.

—Relations of Density—

In all case studies, it is verified that smaller spaces are related to quicker functions, usually bathrooms and kitchens. The larger spaces are those related to social functions, usually living rooms or collective spaces. Even larger kitchens are usually associated with a repositioning of the house's social functions to this space very often in close relation with a smaller size of the living room, and sometimes with the nonexistence of a dining room. The small size of rooms can be explained by the fact that only one person usually inhabits them. It is therefore assumed that the functions associated with denser spaces tend to be quick, favoring the functions associated with less dense spaces.

	BFE1	BFD1
BFE1	5	7
BFD1	1	5

Figure 08.5
Example of relations of density.

The density of each space-function is calculated through the division of its area by the number of probable occupants. At the scale of the apartment, the building, and the neighborhood, this number is calculated assuming that each bedroom has one occupant, with the exception of the bedroom suite, which has two, and that all inhabitants use all areas-functions, with the exception of bedrooms. It is believed that the low density of bedrooms in a part of the case studies has consequences for the integration and use of the social areas of the house. This method is used for all case studies, even though it is very likely this would not always be verified, and that the density in social housing is likely to be higher. This option is adopted due to the impossibility of empirically knowing for each case study the average number of inhabitants by apartment at the time it was built. Unlike what happened on relations of mobility and visual relations, here the value, which expresses the lowest possible relationship between two areas-functions, is five and can be verified between two areas-functions with approximately the same density, or between an area-function and itself. Above this value, the relationship is positive—A is less dense than B, “pushing” towards it and establishing a positive relation with it—and under this value the relationship is negative—B is denser than A, establishing a negative relation with it. An individual in A tends to move to B, but an individual in B tends to stay there.

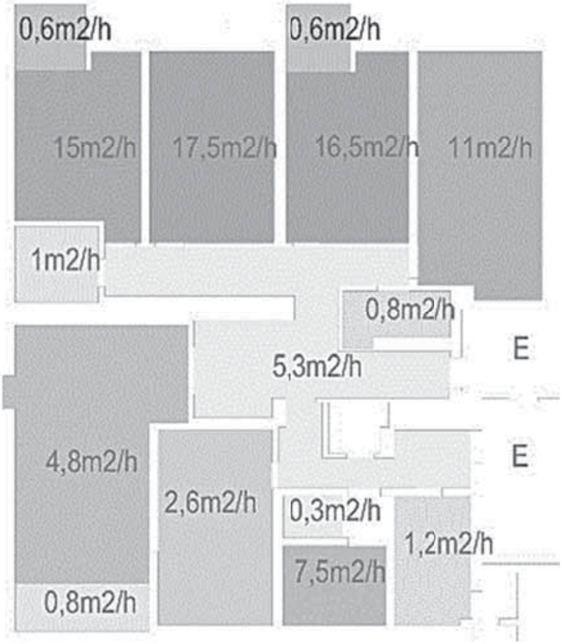

Figure 08.6
Example of a density map.

For a more intuitive understanding of density relations, values between minus five and five could have been used, zero being the lowest possible relationship between two spaces, negative values negative relations and positive values positive relations. However, due to the necessity of being able to put the values of mobility, visibility, and density in relation cohesively to form concepts of segregation and privacy, the values expressing the relations of density followed the general rule and were kept within the zero to ten range.

The relation between densities depends on how more or less dense an area-function is in relation to another, and the way this relation is translated in values from zero to ten is represented in Figure 08.5. The resulting table does not have the same meaning in a vertical reading as it has on a horizontal one, as a given area-function A can relate with another B in two different ways: how much A "pushes" towards B (with a negative value, from zero to four, if A is less dense than B), and how much A "attracts" from B (with a positive value, from five to ten, if A is denser than B).

A vertical reading shows how much each vertical area-function "attracts" to each horizontal one. The average of these values results in a value of attraction (a), the average of how much each area-function "attracts" to all the others. A horizontal reading shows how much each horizontal area-function "pushes" towards each vertical one. The average of this values results in a value of repulse (r), the average of how much each area-function "pushes" towards all the others.

Concepts

The relations of density, visibility, and mobility that the different areas-functions establish with each and all the others make it possible to define five values inherent to each one of them. These reflect values of social interaction of an area-function in relation to all the others, which translate to values of Privacy (P) and Segregation (S). The definition of these concepts in this context, with others that were essential to the construction of this methodology of analysis, was a fundamental step to the analysis of the case studies. Here, General Integration (IG), Control (C), Privacy (P), and Segregation (S) are spatial concepts that depend on the relations between the functions of dwelling. They are also concepts that, defined by the different values that can be taken from the relations of density, visibility, and mobility, can be defined mathematically. The relative importance of each one of these values is not yet known, and it would be impracticable and beyond the objective of this study to learn the necessary sociological and behavioral empirical basis to do so. For this reason, the formulas defining concepts like Privacy and Segregation are constructed so that they are the most flexible and open as possible, easily adaptable to new knowledge.

It is not a goal of this study to develop definitions of General Integration, Control, Privacy, and Segregation that rigorously reflect reality. Instead, it aims at the construction of a basis that makes it possible, with access to knowledge generated in different fields of knowledge, to redefine these concepts, so that they can grow closer and closer to reality.

General Integration is defined as such:

$$IG = \frac{P_1 a + P_2 ev + P_3 cv + P_4 c}{100} \qquad P_1 + P_2 + P_3 + P_4 = 100$$

The more permeable a function is in relation to all the others, the more it sees and is seen, and the less dense it is and, therefore, the longer the activity to which it is associated is, the more it is integrated in the spatial system of which it is a part. However, because there were no data available to make it possible to define how important these characteristics of an area-function are in relation to each other and in which way, it was defined that each one counts as a quarter of General Integration. These values can be easily altered in light of new knowledge. For this particular study, General Integration was calculated as follows:

$$IG = \frac{25a + 25ev + 25cv + 25c}{100} \qquad P_1 + P_2 + P_3 + P_4 = 100$$

If, for example—and this being a simplification of the potentialities of the method and the ways it can be developed,—a future sociological study of housing demonstrates that accessibility is more important for the definition of the General Integration of an area-function, the formula could be easily altered for something that would reflect it better.

$$IG = \frac{10a + 25ev + 25cv + 40c}{100} \qquad P_1 + P_2 + P_3 + P_4 = 100$$

Such can be applied to all the formulae defining the values of social relations developed for this research.

The *Control* of a determined area-function is defined as such:

$$C = \frac{P_1 cv + P_2 c + P_3 p}{100} \qquad P_1 + P_2 + P_3 = 100$$

This concept is based on the idea of control and power as defined by Thomas A. Markus who, in his analysis of various buildings serving different functions, verifies that the deeper a space is from the outside of the spatial system to which it belongs, the greater are the power and control of its inhabitants.[5] So, the more an area-function can access others, the more it sees others and the deeper it is from the outside, the greater its control over the social relations within the system it is a part of. Throughout this study this concept has been verified multiple times, with apartments showing a tendency to have high levels of control associated to "living" and "sleep" areas-functions, and lower levels of control associated to services, the kitchen or the maid's bedroom.

The *Privacy* of a determined area-function is defined as such:

$$P = 10 - \left(\frac{P_1 ev + P_2 c + P_3 (10 - C)}{100} \right) \qquad P_1 + P_2 + P_3 = 100$$

The following define a value of *Exposition*, inverse of *Privacy*:

$$E = \frac{P_1 ev + P_2 c + P_3 (10 - C)}{100} \qquad P_1 + P_2 + P_3 = 100$$

This means that the less others can see an area-function, the less permeable it is in relation to all the spatial system and the greater its control is, the more private it is. Throughout this study, this concept has been verified multiple times, with apartments showing a tendency to have high levels of privacy associated to bathrooms, and the lowest levels of privacy associated to social functions, as "living" and "eating."

The *Segregation* (S) of a determined area-function is defined as such:

$$S = 10 - \left(\frac{P_1 a + P_2 e + P_3 c + P_4 C}{100} \right) \qquad P_1 + P_2 + P_3 + P_4 = 100$$

The following formula defines a value of *Integration* (I), the inverse of *Segregation*:

$$I = \frac{P_1 a + P_2 e + P_3 c + P_4 C}{100} \qquad P_1 + P_2 + P_3 + P_4 = 100$$

This means that the less the others within the same system see a determined area-function, the less accessible it is, the shorter the use associated with it is and the less control it has over the system, the more segregated it is. Throughout this study, this concept has been verified multiple times, with apartments showing a tendency to have high levels of segregation associated to services, and lower levels of segregation associated to either bedrooms or social areas. These concepts were developed from premises from other methods and sociological studies, as well as inevitable intuitions of common sense, and developed in parallel with the formal analysis of the different scales of the case studies, being restructured when needed. A great correspondence between the results and the knowledge acquired a priori was verified, and so it was considered that these are relevant and capable of providing an interesting analysis of the entirety of the case study.

Case Study

Throughout the 20th century in Porto, different housing experiences can be observed. From the individual house as propaganda, heritage of the First Republic and a basis of the dictatorship's ideology, the first experiences on collective housing following more or less collectivist models, the large social neighborhoods, passing through a moment of great public investment on collective housing after the Portuguese revolution—during which a movement is born, which, in the North, presents itself as a going back to the ideals of proletarian individual housing—to the almost complete disappearance of public promotion of housing and, nowadays, even of private investment.

The field of different ideological conflicts and architectural experiences, the evolution of collective housing in Porto between 1933 and the present day appears as a privileged space for how housing form reflects society transforming moments. Going through the studied moments, it can be verified in Porto, a first experience by the fascist regime, which glorified family and private property through the creation of working class communities in the periphery, strongly self-regulated, and hugely segregating to the outside, which are quickly abandoned for an inevitable appropriation of the models of vertical collective housing in a strategy based on the destruction of the existent communities in the center of the city. In an exceptional moment in the city's history, following the revolution that ended the fascist regime, it was attempted to strengthen the connection between working class housing and the city. This happened through an alliance between housing policies and urbanism, making it possible to build better structures for the suburban neighborhoods and those in peripheral cities (it is noteworthy how these neighborhoods present the lowest values of segregation of the near city of all the case studies), but also through an attempt to bring the proletarian classes back to the center, maintaining the existent communities. However, ending up as incredible segregated clusters in the city, the contradictions of doing so at reduced costs were apparent.[6]

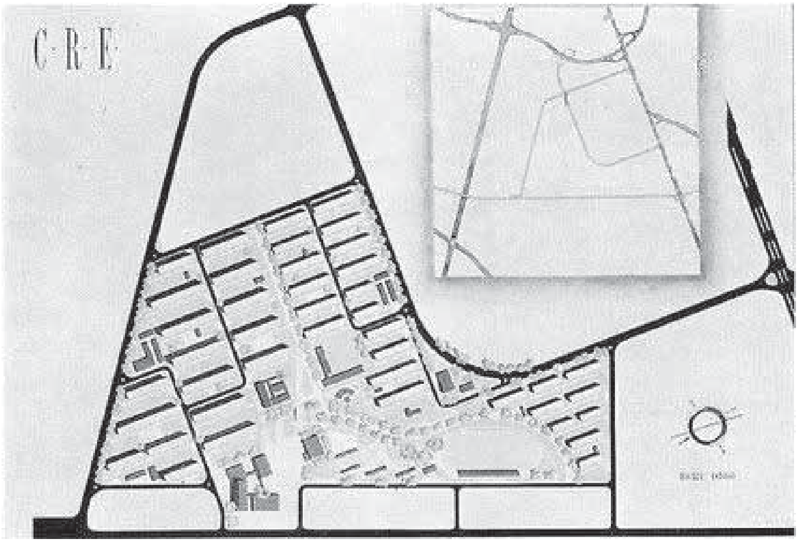

Figure 08.7
Plan of Unidade Residencial de Ramalde.[7]

According to how the values of social interaction varied throughout the century, it was possible to conclude, through the analysis of the case studies and from a global vision of privacy and segregations values at different scales throughout the time, that there was a progressive individualization of the family in an apartment, which segregates the outside. At the same time, when, in the later decades of the twentieth century, both public and private promotion of housing abandon collective functions outside the apartment, the values of segregation of the outside at the scale of the building also go up. Even though the objective of the analysis of the case studies was mostly to understand general tendencies of the studied timeframe, it was also possible to discover some curiosities. These seem not to be simply formal anomalies as they appear in periods where architects were especially aware of their roles and consciously ideologically positioned to be able to, in the context of the complexities and contradictions of a determined historical context, have a great power to influence at least the specific responses of their time. To illustrate what these can be and better demonstrate the potentialities of the developed methodology, two examples from the second half of the 20th century were chosen.

PRIVACIDADE		SEGREGAÇÃO	
RVS1	4,4	RVS1	5,4
RVS2	4,5	RVS2	5,3
RVS3	4,2	RVS3	5,0
RVS4	4,1	RVS4	5,2
RVS5	4,3	RVS5	5,0
RVS6	4,4	RVS6	5,1
RV?1	5,0	RV?1	5,0
RE	6,1	RE	6,8
RC	4,9	RC	5,7

Figure 08.8
Values of privacy and segregation in Unidade Residencial de Ramalde.

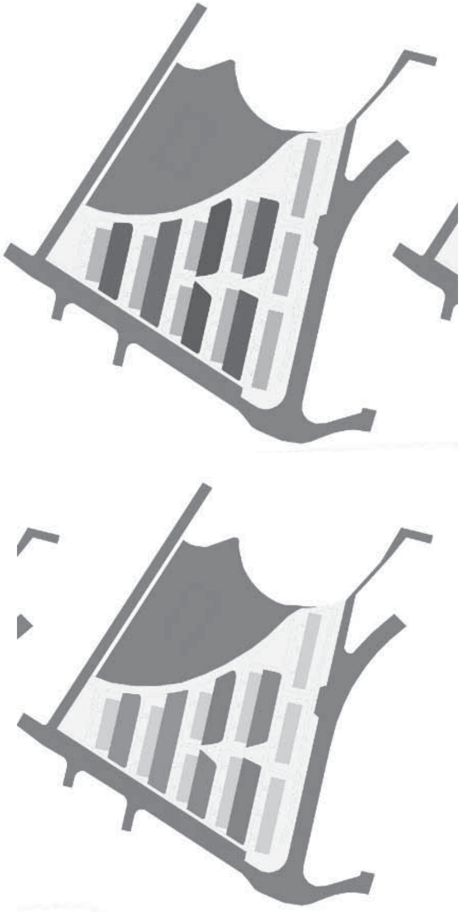

Figure 08.9
Maps of privacy and segregation in Unidade Residencial de Ramalde

The first (Figure 08.7) is a modernist neighborhood of social housing from the 1950's, about which the architect, Fernando Távora, stated as having the objective to allow only the minimal private life.[8] Indeed, the analysis of the relations between the area-functions of the neighborhood seems to indicate he was successful in doing so. Very atypically to what was verified in the studied timeframe, the housing buildings (RE) are the more segregated part of the complex, while the close city (RC) shows relatively low values of privacy and segregation.

The second example appears in the post-revolutionary period, involved in a movement where the architects tried to claim the working class's right to live in the city center and worked in close proximity with the future inhabitants of the project (Figure 08.10).

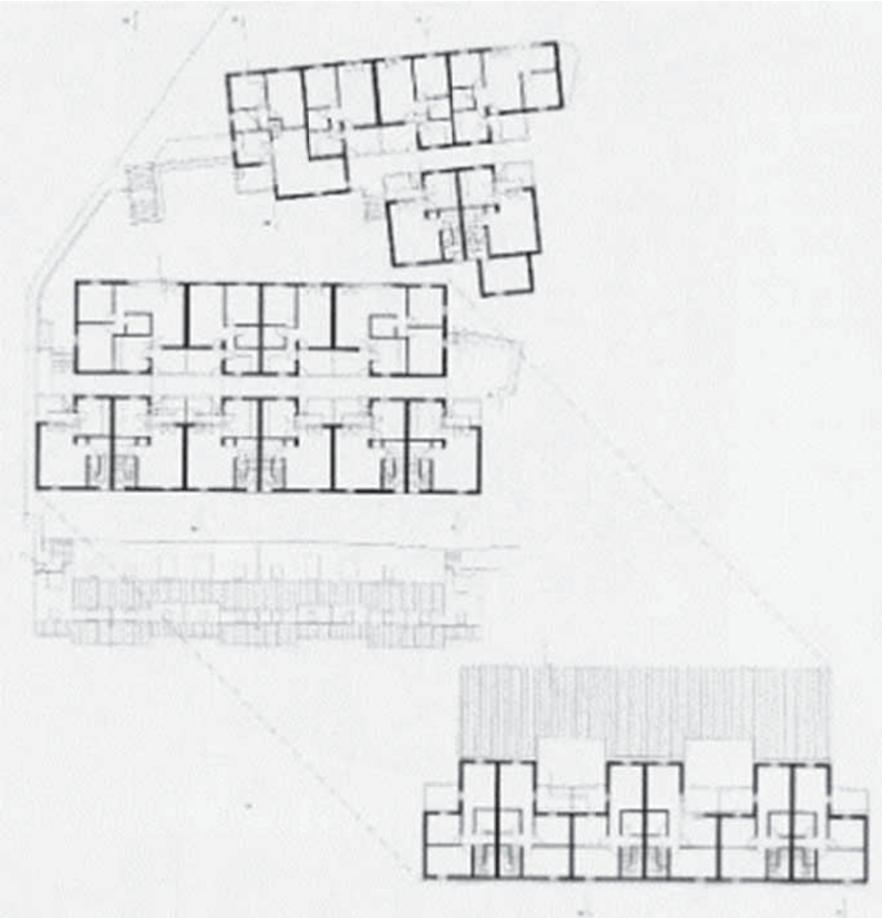

Figure 08.10
Bairro do Leal.[9]

As the plan seems to indicate, the surrounding city is, in the case of the Bairro do Leal, highly segregated in relation to the neighborhood. However, with a low value of privacy at this scale, it seems that the complex system of transition spaces—perfectly understandable in the justified graph—exists not to further the distance between the neighborhood and the city, but to assure its privacy.

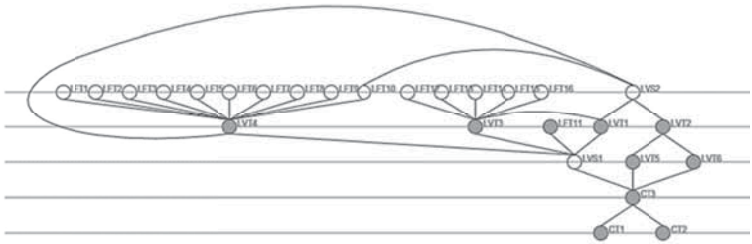

Figure 08.11
Mobility graph of Bairro do Leal's neighborhood

PRIVACY		SEGREGATION	
PRIVACIDADE		SEGREGAÇÃO	
LVS1	5,1	LVS1	5,1
LVS2	5,1	LVS2	5,8
LF	5,4	LF	4,4
LC	4,9	LC	6,2

Figure 08.12
Privacy and segregation in Bairro do Leal's neighborhood.

PRIVACY		SEGREGATION	
PRIVACIDADE		SEGREGAÇÃO	
LFE1	5,7	LFE1	6,0
LFR1	5,7	LFR1	6,0
LFC1	6,1	LFC1	7,1
LFB1	8,0	LFB1	7,0
LFD1	8,4	LFD1	6,4
LFD2	8,2	LFD2	6,0
LFD3	8,1	LFD3	5,7
LV	8,1	LV	7,1

Figure 08.13
Privacy and segregation in Bairro do Leal's apartment.

At the same time, and in the context of a period of particularly intensive research in the field of housing regulation with the objective of establishing the rules of dignified housing and taking into account the social changes in the role of the woman inside the domestic space, it's noteworthy that, even though it presents some of the usual characteristics of the typology that had been repeated since the beginning of the modern movement—where the social functions are the less private areas while the bedrooms are the most,—in this case the bedrooms are also the more integrated spaces, which suggests a favoring of individual life. It's also a particular case of public housing where the kitchen is the most segregated area of the house, a common characteristic of higher-class housing, and usually associated with the existence of an intern maid.[10]

Figure 08.14
Plans of privacy and segregation of Bairro do Leal.

Discussion

This research aimed at exploring and developing concepts present in theories of analysis of the built environment, stepping away from these methodologies both in premises as in approach. Although profoundly based in the experiences of space syntax, the construction of a new methodology based in a critical analysis of this theory, which searches to question and respond to certain of its aspects, necessarily leads to new concepts and to the redefinition of some.

Coming from the basis provided by different theories of spatial analysis, the search for a greater approximation to social sciences and of a smaller abstraction and simplification of architectural space resulted inevitably in a method that is immediately less scientific, less self-coherent, and unarguably more amateur. Also, because of this attempt to conciliate a formal and quantitative methodology for spatial analysis with the way people use architecture and function inside it, the association of this study with sociological, behavioral, and anthropological work could only validate the developed method.

It is apparent that with the decision to develop something new instead of applying methodologies that have been in development for decades, the conclusions of the analysis risk being less reliable and less complete. The objective of the research at the point of the development of this chapter was not the development of a methodology of formal analysis of the architectural forms that was correct in its relationship with reality, but the construction of a theory and self-coherent mechanisms that make the development of methodologies capable of a reliable analysis of reality possible. Future work will aim at addressing present flaws to materialize a more systematic and coherent methodology.

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CHAPTER NINE

A GATHERED METHODOLOGY: TOWARDS ENHANCING ADAPTABLE LEARNING SPACES

CAROLINA COELHO

Introduction

This chapter aims to develop a comprehensive and gathered methodology for enhancing adaptable learning spaces by converging outputs from proven yet distinctive methods of spatial assessment into an original and contemporary approach. For this purpose, the first milestone will be to explain the significance and relevance of the concept of adaptability, its specificity when applied to the school brief, along with literature references on the state-of-the-art. The second milestone will present an overall portrayal of the methodology by briefly introducing each of the approaches and respective inputs towards a more supported definition of an adaptable learning space. At this stage, the case study will be introduced in order to subsequently apply each of the approaches in a real-life scenario. The third milestone will provide a detailed description of the specific methodology in its sequential stages and the results of its application on the case study presented. Finally, expected outcomes will acknowledge the potential relevance of activity allocation, spatial morphology, experience, and appropriation towards effective spatial occupancy, whose feedback can be valuable evidence when designing or rehabilitating educational facilities.

The Relevance of Adaptability for Learning Spaces

> *If the idea of designing buildings as completed compositions, like sculptures, has long ceased to be relevant, this applies pre-eminently to schools, which are more susceptible to the restlessness of our demanding society than any other building.*[1]

The concept of adaptability has been interpreted by a broad range of authors and applied to different briefs, such as dwellings,[2] hospitals,[3] and office buildings.[4] In fact, DEGW values adaptability over flexibility, considering that "adaptability is a much better—and much cheaper—term to use because it means including within the design the capacity to add features later: planning for change, rather than catering for anything that might happen."[5] This is shared by Blyth and Worthington, who support adaptability as a significant concern to be acknowledged in the design: "Adaptability implies the ability to change, whilst still leaving options open and not being unnecessarily costly or complicated."[6]

Particularly, on educational spaces, adaptability assumes extensive significance, during the design process, but also along all the building's lifecycle through individual or collective appropriation. Indeed, the possibility of a school to be adapted to future uses, and yet still unpredictable needs, while evolving along with them will provide a thorough spatial answer from the building, will have impact on student achievement, and will represent a more sustainable and lasting investment.

Amongst all interpretations, for the current research, adaptability is regarded as "the ability of the built form to maintain compatibility, between activities and spaces, as those vary,"[7] following OECD's definition as "essentially large magnitude/low frequency change."[8] Furthermore, this research is also supported by Fawcett's studies on assessing adaptability,[9] Herzberger's built and written works on Space and Learning,[10] and authors of reference on contemporary learning spaces and practices, user research, and assessment methods on educational facilities like Sanoff[11] and Lippman.[12]

Additionally, within the same concern with tackling the unpredictability of future demands, Fawcett refers to "lifecycle options" that "transfer decision-making from people in the present to people in the future who will know more about the changing state of the world."[13] Moreover, other analogous concepts can be pondered like "polyvalence"[14] for allocating different uses, or even "change readiness"[15] to answer more thoroughly to changing needs. Furthermore, OECD considers "facilities that support today's education needs, facilities that serve as a learning tool for students and are responsive to curriculum changes"[16] to be exemplary. Adaptability is therefore a significant requirement for a school to continue to pursue and potentiate the evolving learning model and its technological approach, crucial for today's framework.

In fact, both physical and psychological features are recognized as proven catalysts for the learning process.[17] Therefore, pedagogical developments in the schools' curricula and in the learning process, along with social changes from the profiles of the school community from the students, educators, school board, staff, and parents, besides the on-going technological achievements, all imply rethinking the learning process and the learning spaces, reconsidering them at several levels like their configuration, technology, and materials. Besides, this contemporary learning paradigm implied not only a reconsideration of the classrooms, but also of the overall school space and the acknowledgment of other active learning environments that "support mobility," "enrich pathways, by (…) providing opportunities for creative interaction" and "blend and blur activities."[18]

Overall, the contemporary learning experience contemplates formal and informal activities occurring in formal and informal spaces in the school. Activities such as group work, formal classes, group presentations, evaluation moments, and general conferences, besides socialization and peer interaction (both in scheduled events during classes, as well as in spontaneous meetings decentralized from the classroom), all represent moments of a thorough learning experience. Thus, each of these activities implies specific spatial features, which will have to be accounted for in the existing and future educational buildings.

In fact, today's schools bear mixed curricular options that add further complexity to the design. Accordingly, adaptable learning spaces accommodate a more extensive range of activities and users, which are able to cope with curricular, technological, and social changes in the long-run, by lessening the frequency of future interventions in the built object due to its pre-perceived provision in the design.

Depiction of Overall Methodology and Presentation of the Case Study

> *Strategic decisions made at the beginning of all design processes (typically, when little information is available) always have a great influence on initial performance and on long-term consequences* (…). *In the subsequent life cycle phases (e.g. in a refurbishment) design also assumes a long-term impact; it must ensure or recreate the adaptability of the building to meet future needs.*[19]

As suggested, if the learning experience takes place in distinct spaces this methodology will also consider a crossing of methods to deliver quantitative and qualitative results on both spaces' formal and informal features. Consequently, this hybrid methodology aims to assess the adaptability of the learning environments by means of three distinct approaches: a space syntax analysis focused on the building's morphology, entropy calculations by means of a mathematical formulation, and lastly the use of qualitative methods such as observation matrices, walkthroughs, and focus groups for a better understanding of spatial experience and appropriation. It will then display conclusions based on the outcomes of each stage. After proceeding with this methodology, educational spaces can be analyzed, assessed, and even ranked according to the possibility of allocating learning activities of distinct nature and undertaken by different users, ultimately concluding on each space's adaptability potential.

Figure 09.1
Quinta das Flores School, Coimbra, Portugal.

To contextualize the presented methodology, it has been originally created from scratch under a Doctoral research that inherently holds a deeper complexity and detail. It has also been applied to a case study for a more concrete explanation of a methodology that is admittedly complex by its several stages and its hybrid approach. Nevertheless, and assuming a simplification of both the stages and the results presented, this chapter aims to provide an overall portrayal of the full methodology and how it potentially reaches a robust conclusion by gathering distinct academic established areas to answer a defined research question for both the theory and the practice in architecture.

Specifically, the methodology has been applied to Quinta das Flores School (Figure 09.1), a Basic, Secondary, and Music school in Coimbra, from 1968. The school went through a modernization process in 2008-09 under the scope of the overall program implemented in Portugal. Besides the general aims from the program that lined all the schools' interventions, for this school the intervention had the specificity of introducing the artistic teaching of both music and dancing, whose spatial requirements are clearly more extensive. For this chapter, the analysis will be restricted to the building built under this modernization program and specifically to the ground and first floors, which are the most representative in terms of activity and user mix.

A Sequential Procedure

Assessing Spatial Morphology with Space Syntax

> *In talking about buildings, we need not only to talk about objects, but also about systems of spatial relations*.[20]

This quote refers to the bond between society and space explored by Hillier and Hanson in Social Logic of Space.[21] In fact, according to its spatial properties, the school enables a particular system of social relations by stimulating encounters, patterns of movement, and co-presence, considering it to be an "educational tool."[22] Therefore, a space syntax analysis plays a critical role, as it focuses on spatial morphology and the concepts of integration, depth, connectivity, visibility, and ultimately intelligibility. This will provide conclusions on the implications of spatial placement towards patterns of natural movement and activity, and users' clusters. Moreover, while considering that learning occurs both in individual spaces and amongst pathways, where diverse spaces are displaced, the promenade through those spaces is also a means towards communication, interaction, and learning between all the school communities. As axial lines cross several spaces, their analysis brings further data to this research because they refer to several potential activities in sequences of natural movement and provide data on "shapeless" and informal environments that hold pedagogical potential. Thus, their acknowledgment considers the learning experience to happen on the spatial layout, crossing both formal and informal spaces. Therefore, this method will be undertaken on convex spaces as individual entities, as well as on a topological relation of spaces by axial lines.

The global and local syntactic properties will be evaluated in charts and graphs provided by DepthmapX after importing the data from the plans to the software.[23] The crossing of both results will provide a broader outlook on the patterns of co-presence, both in moving and static activities, and more fully describe the relation between morphology and function(s). This has been applied to the plans of the new building of Quinta das Flores school (Figure 09.2), concluding that the most integrated space on the ground floor is the main hall, which welcomes all the users, enabling spontaneous encounters, and which also promotes social gatherings and pedagogical events for an enlarged school community. Whereas on the upper floor, the main corridor is also the most integrated space, but as it is narrower, it enables mostly circulation rather than static activities.

The analysis of both integration and connectivity indicates that the highest values belong to the ground floor's axial map rather than the analysis of the same floor done by means of a convex space map that inherently shows the highest values in mean depth. Therefore, the axial line that gathers all the longitudinal spaces is more representative of the whole system than the corridor alone as a convex space. Afterwards, intelligibility scattergrams, as a second order measure, can be achieved by correlating integration and connectivity, and understanding which floor's layout is best comprehended and less "labyrinthian."[24] In this case, it is the ground floor's axial line map that provides higher levels of intelligibility proven by the scattergram's regression line and determination coefficient. This is significant since this is actually the floor used by all as an interface between inhabitants and visitors in circulation pathways towards each one's destination in the system.

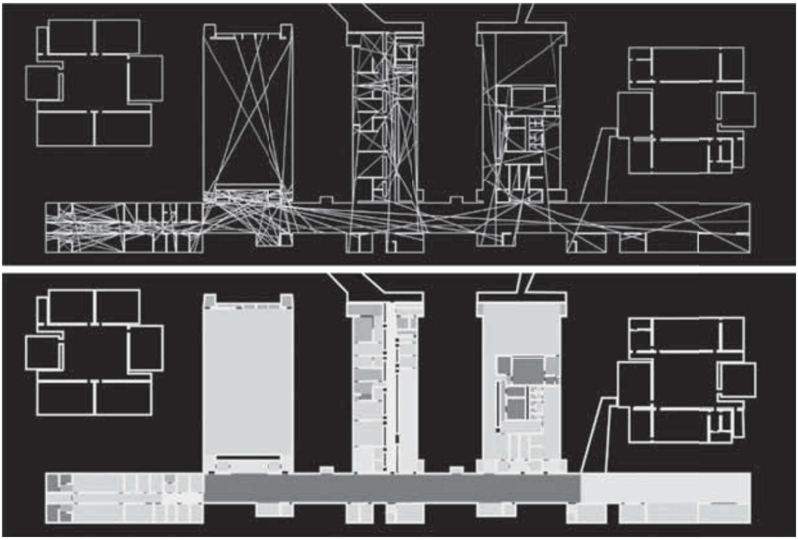

Figure 09.2
Axial line and convex space map of the ground floor for integration.

Weighting Entropy by a Mathematical Formulation

The entropy of each space will be calculated by means of the mathematical formulation defined by Shannon,[25] under the context of information theory, which was later studied by Jaynes and Tribus.[26] Jaynes considers "'entropy' and 'uncertainty' as synonymous,"[27] which can be transferable to the case study as the uncertainty of an activity allocation to a space. This, ultimately, implies that a higher entropy space has a wider range of potential activity allocations, whereas a space where the uncertainty/unpredictability about which activity is currently happening is lower will mean that it has a smaller number of potential allocations. Fawcett's studies represent a benchmark on the state-of-the-art for this approach, namely his Doctoral Thesis, *A Mathematical Approach to Adaptability in Buildings*, on calculating adaptability as a "numerical value" and matching adaptability and entropy,[28] which he defines as "looseness of fit."[29] From these studies, entropy becomes close to an adaptability index. Following Krüger's studies, maximizing adaptability will mean determining the feasibility matrix that corresponds to the highest number of correspondences between spaces and activity allocations,[30] which can be provided by maximizing entropy by means of a mathematical expression as proceeded in this methodology.

By producing a feasibility matrix displaying activity allocation per space, it is possible to weight the entropy of each space. The application of the formulation will present a figure linked to each space. These results can be crossed with the actual occupancy of that space, concluding on whether it is holding an effective and full usage, under or over the initial brief. This methodology is supported by the studies on building adaptability representative of the state-of-the-art, but critically projects them to the current paradigm of the learning process and learning spaces. Following Hertzberger's concept of "Learning Street,"[31] another novelty introduced by the research underlying this chapter is the analysis of the adaptability potential of the learning environments, within a broader definition, already considered in the previous procedure. After the analysis of convex spaces and axial lines through space syntax, entropy will weight not only all the convex spaces, but it will also provide an entropy value to the axial lines recognized in stage one of the methodology.

This chapter introduces two original concepts on calculating entropy for axial lines: "axial line entropy" defined by "the sum of the entropy of all convex spaces intersected by this axial line" and "average axial line entropy" "calculated, by dividing the axial line entropy by the number of convex spaces intersecte."[32] When the space syntax analysis is paired with mathematical entropy calculations for each space, conclusions can be achieved on its quantitative allocation potential, assuming that higher entropy implies a more adaptable space. The paralleling of both approaches may also conclude on the relevance of these variables towards the actual use of a particular space. E.g.: if space x and y share the same spatial features and display the same entropy levels, but present different values of integration, depth, and connectivity, despite having a similar potential to allocate activities, their actual use may differ because of their spatial morphology within the school system. The process of weighting the entropy has been done by a sequential production of matrices and calculations, and, ultimately, Shannon's entropy formulation, $S = -\sum pi \ln pi$, has been applied to all these spaces presenting an entropy figure for each space that can be ranked and analyzed (Figure 09.3).

For the case study, the spaces with the highest entropy are spaces that hold several features that provide them with the potential to shelter both programmed and non-programmed activities, group and individual practices, of external and internal uses. On the contrary, the spaces ranked with the

ENTROPY CALCULATIONS	
space	value
18 library	2,881
29 orchestra room	2,873
30 music studio	2,873
16 auditorium	2,872
13 spare space	2,834
39 generic classroom	2,821
38 science lab	2,816
37 dance studio	2,58
17 auditorium cafeteria	2,475
20 dinning room / refectory	2,475
1 main hall	2,469
19 cafeteria	2,469
40 common living space	2,469
31 (individual) music training room	2,426
32 teachers' office for meeting students	2,398
36 psychologist's office	2,254
25 students' room	2,023
41 teachers' office	2,023
42 teachers' meeting room	2,023
24 teachers' room	2,02
26 secretariat	1,772
23 staff room	1,386
33 students' shop	1,33
34 photocopy room	1,255
2 access - corridor	1,099
3 vertical access - stairs	1,099
4 vertical access - elevator	1,099
5 entrance / outdoor access	1,099
6 reception desk	1,099
7 ticket office	1,099
8 restroom	1,099
9 dressing room	1,099
10 locker room	1,099
43 auditorium supportive spaces	1,099
11 storage	0,693
12 indeterminate supportive space	0,693
14 vault	0,693
15 archive	0,693
21 kitchen	0,693
22 kitchen storage	0,693
35 parent council room	0,693
27 administration offices - regular teaching	0,637
28 administration offices - artistic teaching	0,637

Library


Orchestra room


Music studio


Main hall

Figure 09.3
Entropy rank of convex spaces.

lowest values of entropy are strictly monofunctional and generally support effective learning spaces. After weighting the entropy of each individual space, the grouped spaces taken into consideration in the sample have also had their total entropy calculated.

Understanding Experience and Appropriation by Qualitative Methods: Observation Matrices, Walkthroughs, and Focus Groups

> *Users are continuously making design decisions as they move scenery around on a day-to-day basis to match changing demands.*[33]

Bearing in mind the previous section, the end conclusion after weighting the entropy for all axial lines considered in stage one is that this is a product of the individual spaces' entropy that each axial line intersects, varying accordingly. After assessing the full and expected activity allocation potential of the spaces, the following procedure will focus on describing their effective occupancy adding further information on spontaneous and non-programmed activities, not referred to in the activity sample used for the entropy weighting. Assuming that each method will provide different conclusions, this methodology resorts specifically to observation matrices, walkthroughs, and focus groups for depicting individual experience and appropriation. Observation matrices aim to recognize patterns of movement and use, and to identify invariables and fluctuations in those patterns. They comprise a report on the nature and density of the activities acknowledged in a specific time-period and repeatedly in several intervals during a whole day.

For the analysis of a school it is relevant to choose the most representative time periods like the morning arrival, lunch break, and evening exit, as well as specific observation days such as a regular school day, the examinations' phase, a vacation's break, and a community event day. It is also done in the spatial clusters acknowledged as the most significant for spatial occupancy, which for this particular school are the main hall, the cafeteria, and the main upper corridor, already recognized as spaces with high entropy and integration. Particularly, for the case study, this procedure also concludes on the diversity of meaningful time-periods for observations due to the numerous extra-curricular activities it holds, and it also acknowledges a wide community of users within each spatial cluster performing activities of different nature. This validates the school's potential to be more often and intensively used. Walkthroughs are repeatedly done with assorted focus groups of the internal school community, each with a common denominator. For this school, it was found relevant to proceed with walkthroughs with students and educators from the regular teaching, students and educators from the artistic teaching, and school staff. This procedure aims to recognize how the school community moves and acts in space and what the main pathways each focus group chooses are.

In the analyzed school, the adopted method holds greater complexity due to the wide variety of users, which also indicates a wide range of distinctive uses. Besides, the fact that there is a strong artistic community that often proceeds with informal or non-programmed activities in a variety of school spaces increasingly broadens the range and nature of the activities into consideration. Afterwards, one person from each previous focus group identified is asked detailed questions to add information on specific situations recognized in the previous walkthroughs.

Focus groups, overall, aim to provide qualitative information on spatial experience, rather than inquiries. In fact, in inquiries the questions placed are limited and often resort to multiple answers, restricting the possibilities of experiencing space to the answers considered and providing mostly a quantitative outcome.

The detail of the questions here is chosen according to the purposes of the research and is done in the form of recorded interviews, with subsequent critical analysis. For this case study, the focus groups consist of a set of students and a set of educators. Generally, these procedures imply that a space can be used for a specific purpose but could also, before management decisions or spontaneous appropriation by the users, hold other activities rather than the original ones from the brief. It also demonstrates that spatial experience varies according to the profile of the community analyzed, which in this case is particularly relevant, because it introduces a wider range of activities to be considered. Besides, this school also enables appropriation, which is quite significant for the creative artistic teaching community when experiencing space, mostly following Hertzberger's outlook that "architecture should offer an incentive to its users to influence it wherever possible, not merely to reinforce its identity, but more especially to enhance and affirm the identity of its users."[34]

Discussion

Having explained the methodology and its application on the case study, and having produced a critical analysis of the data gathered on the individual approaches from specific academic fields, the final output of this research aims to display an insightful outlook on the possibility of analyzing an educational space by these several procedures, but foremost it aims to demonstrate its relevance and originality when used within a hybrid methodology.

Assuming the specificity of today's active learning environments, whose configuration can widely vary according to the diverse range of activities that contribute to the learning process, it has been considered relevant to analyze the school building not only by its convex spaces but also to consider the pathways as possibilities for learning. Hence, the relevance of this methodology also lies in the correlation between convex spaces and axial lines within a space syntax and an entropy approach, followed by a comprehensive analysis of the potential correspondence between the individual results.

Overall, the methodology identifies the spaces whose individual values and overall correspondence between all approaches are higher in order to inform on the most significant adaptable environments. For a practical application of this methodology, it has been applied to a particular case study with a wide scope of spaces, activities, and users, and a high need for spatial adaptability. The data gathered in each sequential stage has been transferred to the next as Schön's "reflection in action"[35] process, ultimately providing a general outlook on the case study's adaptability. On stage one, charts and graphs were produced on the axial lines and convex spaces of the sample, for local and global syntactic properties, to further understand part-whole spatial relationships and space's individual representativeness towards the whole system. Then, the entropy of each convex space and axial line was weighted and charts were made with the end results. Generally, spaces with recognizable values of entropy also represent some of the most integrated and connected ones, and the most significant for users when experiencing space, such as the library and the main hall, spaces with high entropy and high integration respectively. This supports a potential correlation between activity allocation, integration, and appropriation, and ultimately towards adaptability. Furthermore, other spaces identified with significant values of entropy, namely the orchestra room and the dance studio, are intersected by the most integrated axial line for that floor; therefore, presenting a strong correlation between syntactic integration and entropy.

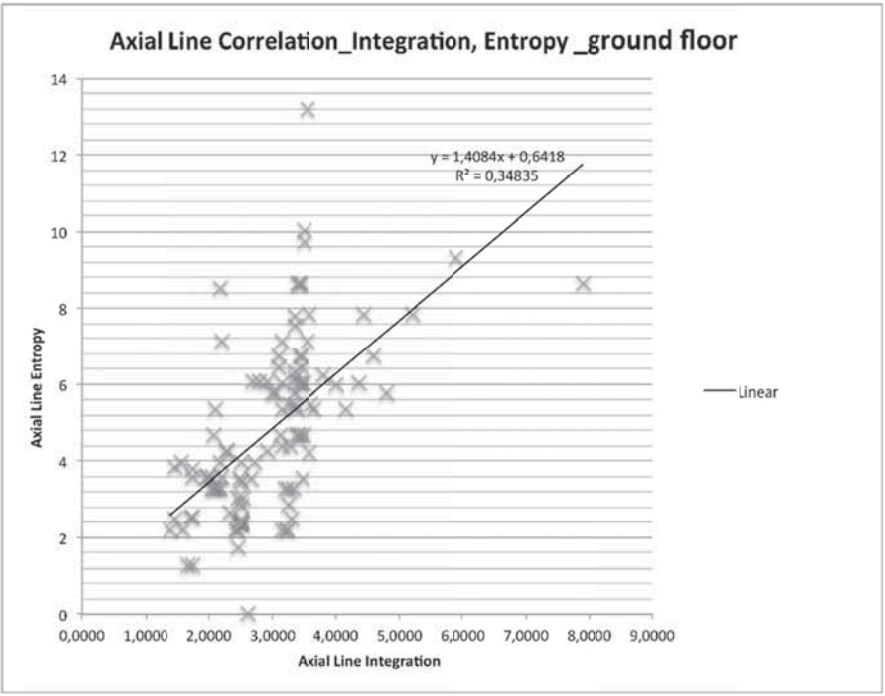

Figure 09.4
Scattergram of the most representative correlation:
Correlation between axial line integration and axial line entropy for the ground floor.

Then, scattergrams were also produced that correlated space syntax's integration with entropy calculations for both convex spaces and axial lines that lead to distinct results. Specifically, for the case study, the correlation between axial lines has proven to be stronger. The regression lines and determination coefficients of the scattergrams pointed out that it is the ground floor, when analyzed by axial lines that holds the highest correspondence (Figure 09.4), which is also the distribution with the highest syntactic intelligibility. This bears significance at a pedagogical perspective as explained earlier. It also confirms a higher possibility of spaces with high entropy, such as the main hall or the cafeteria, to be experienced by users in various ways, namely for performances of the artistic and regular teaching or for external events, and it also highlights the relevance of informality and non-programmed activities particularly for this school's curricula and students.

Finally, and recognizing the importance of the educational spaces towards learning, this chapter concludes on the potential correspondence between spatial morphology and high entropy levels regarding actual spatial usage and building performance. These outcomes provide in-depth data on the potential overlapping of attributes, spaces, and activities towards adaptability, whose input can inform future projects on the design strategies that will affect the building's occupancy, ability to cope with change, and overall lifecycle extent.

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CHAPTER TEN

GRAPHIC USER ENVIRONMENT FOR AGENT-BASED MODELLING AND SIMULATION

TIAGO GOMES

Introduction

The contents within this chapter result from a master dissertation on applied technology to space analysis and movement simulation in architectural and urban contexts. The conceptual framework of it is that as technology evolves, one (as a part of it) is led to adapt and follow it (within big webs—like social networks—that connect us). One must (now, more than ever) rethink the way we conceive all these new progressing concepts and reconsider how space can be related to these innovative notions, and in what way does it adjust to new behaviors of conceiving architecture. More than just drawing with ruler and compass, making rigid lines and rigid figures, we now work with dynamic systems.[1] This leads us to a new way of approaching architecture. One must make use of new tools to accommodate the need to conceptualize our perception of space. This must be one of the present-day architect's concerns, not only to use these tools to simplify the process of designing architecture but to turn the whole design process dynamic by assembling new methods and truly reformulating the entire spectrum of methodologies that nowadays are taken for granted. You have to go to it the difficult way. You have to go to it the consistent way.[2] This way of thinking is the foundation of this research. The experimental way of restructuring the mental processes made on the approach to the design process from its inception to its production.

Processing is a creative programming platform (IDE/Integrated Development Environment) supported by Java language, developed by Ben Fry and Casey Reas, which assumes the purpose to combine different programming (and increasingly diverse) areas of digital arts through structuring responsive visual media applications and the way they interact.

Having had the educational purpose quickly encouraged originally, the participation of growing communities increased its development in areas such as performing arts, kinetic arts, and data visualization interactive real-time experimental architecture among other fields of artistic creation and applied research. Within an architectural perspective, there is the in-depth research to the generative level design and implementation of limitations associated with "traditional" methods, where processing demonstrates great potential, allowing the user (architect-developer) to define specific dynamic applications that allow the processing conditions and complex rules in creating certain architectural objects to be put into practice.

The first step was to create a tool that would deal with Agent-Based Modelling (ABM) for studding emergent behavior of cities at different levels and scales.

Agent-Based Modelling and Simulation

What Are Autonomous Agents? What Are They For?

An agent is an abstract digital entity that moves in a certain space and time following a certain set of rules that interact with their environment. These rules are interconnected with other agents (neighbors) and the environment it is embedded in. The term *autonomous agent* generally refers to an entity that makes its own choices about how to act in its environment without any influence from a leader or global plan.[3] To better understand the concept of what is an agent and how it works, a closer and hypothetical approach to this entity will take place. An agent is a point in a three-dimensional space, not a static point but a dynamic one. Therefore, it is a point that moves in three-dimensional space. The next step is to question:

—Where/why/when/how does the point move?—

One can start by imagining a point traveling endlessly throughout space in a straight direction, although it is not an autonomous agent yet, it is a start. For an agent (or a set of agents) or any dynamic geometrical shape to exist in the environment it must be created in a certain moment in time at a certain location in space with a certain initial velocity. At the time = 00:00:00, an initial set of 100 agents at the initial location = (0, 0, 0) with an initial velocity of one (in a random direction) will be created in our constrained space (Box [600,600,600]).

In the real world, we cannot have the same object in the same location at the same time but in the *agent world* this condition can happen. Therefore, 100 points are now at the given location with a certain velocity. As time moves on, they start to spread in a random direction. The most intricate thing about agents it is how they behave with each other and the environment. For this to happen, one must create a set of rules for them to interact. Now, a rule to the behavior will be added. The name of one of the rules is *separation* and it will bring some awareness to the set of agents. As the name implies, this rule's purpose will be to provide the agents with the ability to separate themselves from each other according to two basic variables: radius and scale. Therefore, if an agent is at a certain minimum distance from another (radius) the separation function will kick in with a certain amount of force (scale). Although separation plays an important role on these agent-based simulations, other types of rules must be implemented so that agents behave in a more natural way. These rules will drastically influence the global reaction of the emergent result. They represent the DNA of a specific set of agents thus must be fine-tuned carefully for a specific situation. Further, in the research, these concepts and what they represent will be explained individually as well as how they work and how they can be used to perform specific tasks.

—Definition of the main rules (structured on Reynolds's work)—

The rules for the simulation can be divided in to two main levels: *i*) Low Level Rules (LLR), *ii*) High Level Rules (HLR). These simple rules will be within the group of LLR as they are at the core of a specific set of agents. The LLR are the simplest rules and the ones that allow for the agents to react among themselves, and the HLR are all other rules that either will allow for the agents to react to external components or to perform specific functions. The amount of these HLR can be endless, since it is for the user to define them, and might become more complex within each iteration. An autonomous agent must follow a specific set of rules that will describe his movement. These rules will define the primary behaviors of our group of agents, and must be defined and controlled by the user. There are three basic rules for the simplest form of an agent to be implemented. These three rules where implemented by Craig Reynolds in 1986 on a simulation called "boids".[4] Using Shiffman's words:

> *In late 1980s, Craig Reynolds (a computer scientist) developed algorithmic steering behaviors for animated characters. These behaviors allowed individual elements to navigate their digital environments in a 'lifelike' manner with strategies for fleeing, wandering, arriving, pursuing, evading, etc. Used in the case of a single autonomous agent, these behaviors are simple to*

understand and implement. In addition, by building a system of multiple characters that steer themselves according to simple, locally based rules, surprising levels of complexity emerge. The most famous example is Reynolds's "boids" model for "flocking/swarming" behaviour.[5]

As it was assumed previously, an agent is an abstract entity that conforms to a set of rules. According to Reynolds, these rules are commonly known as steering behaviors. These are the basic steering behaviors used in this graphic user interface. The next paragraphs explain it better through the words of a reference author in the area. Quoting Reynolds, it is important to refer to the following:

Wander (…) *is a type of random steering. One easy implementation would be to generate a random steering force in each frame, but this produces rather uninteresting motion. It is twitchy, and produces no sustained turns. A more interesting approach is to retain the steering direction state and make small random displacements to it in each frame. Thus, at one frame, the character may be turning up and to the right, and on the next frame; it will still be turning in almost the same direction. The steering force takes a random walk from one direction to another. To produce the steering force for the next frame, a random displacement is added to the previous value, and the sum is constrained again to the sphere's surface. The sphere's radius (the large circle) determines the maximum wandering strength, and the magnitude of the random displacement (the small circle) determines the wander rate*.[6]

Another useful concept is *cohesion*—going back to Reynolds, he says that,

steering behavior gives a character the ability to cohere with (approach and form a group with) other nearby characters. Steering for cohesion can be computed by finding all characters in the local neighborhood, computing the "average position" (or "center of gravity") of the nearby characters. The steering force can be applied in the direction of that "average position" (subtracting our character position from the average position, as in the original boids model), or it can be used as the target for seek steering behaviour.[7]

Reynolds also sets the framework to the motion of *alignment*.

Steering behavior gives a character the ability to align itself with (that is, head in the same direction and/or speed as) other nearby characters. Steering for alignment can be computed by finding all characters in the local neighborhood, averaging together the velocity (or alternately, the unit forward vector) of the nearby characters. This average is the "desired velocity", and so the steering vector is the difference between the average and our character's current velocity (or alternately, its unit forward vector). This steering will tend to turn our character so it is aligned with its neighbours.[8]

Finally, *separation*—Reynolds says that,

> *steering behavior gives a character the ability to maintain a certain separation distance from others nearby. This can be used to prevent characters from crowding together. To compute steering for separation, first a search is made to find other characters within the specified neighborhood. This might be an exhaustive search of all characters in the simulated world, or might use some spatial partitioning or caching scheme to limit the search to local characters. For each nearby character, a repulsive force is computed by subtracting the positions of our character and the nearby character, normalizing, and then applying a 1/r weighting (the position-offset vector is scaled by 1/r 2). 1/r is just a setting that has worked well, not a fundamental value. These repulsive forces for each nearby character are summed together to produce the overall steering force.*[9]

It is relevant to complement the above references to Reynolds's topics with a brief highlight to "Plethora-project:" an academic open source project created by José Sanchez. One of the components of his work is a specific processing library called "plethora library for processing." It deals with agent-based rules and gathers the main components used when dealing with the study of emergent behaviors. This library was used within the research to implement the agent-based rules used in the developed simulations.

Basic Framework of the Graphic User Interface

For dealing with the above rules set by Reynolds, an interface was created. For a simulation to be implemented, a set of initial conditions must be created according to a specific strategy and according to the results intended to be achieved. The user is presented with an environment of creation (Figure 10.1). A graphic user interface that will allow the control of lower level functions of the software is used. From that point, a strategy must be created using the functions interactively and dynamically to achieve a certain and often unexpected result. A set of functions and components are available for the user to activate and control in real-time. For the user to take advantage of the system, it is necessary to know each function and what it means in an abstract way. This will allow any user to comprehend and to be able to be comprehended when communicating with either the system itself or any other user. This process will allow the articulation between the native components (agents, attractors, deflector, walls, lines, box, and terrain) and complex components like external geometry and other dynamic components.

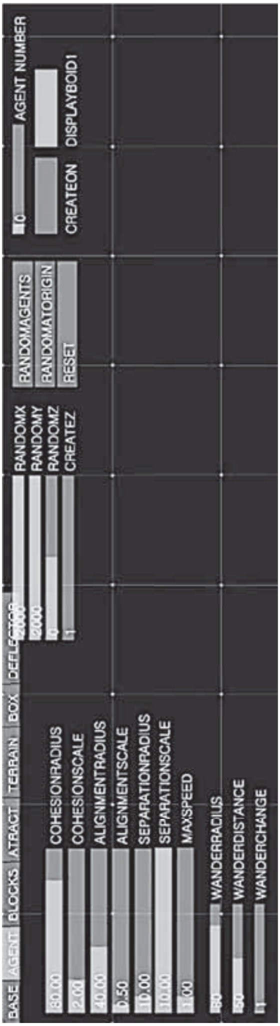

Figure 10.1
Graphic user interface agent tab.

This section was about how the multi-agent-based-system operates—from basic semantic interoperability that contains the native components (which are the individual elements that compose the operational structure) to the complex iteration that sets the interoperability between the native components, the external components, and the user interaction.

Outputs from the Graphic User Interface

Some of the results were highly unexpected as they depended on the initial strategy of each experiment as well as other intricate emergent events that one could not have predicted in the initial state. The main goal was to allow the user, after running through a set of trials, to obtain shapes and concepts that would allow for a further understating of certain qualities of specific spaces in an abstract way for further interpretation and translation. It is possible to translate the shape behaviors to *real-world* concepts like flow, tension, looseness, proximity relations, and others. In Figure 10.2, the process had two stages: (a) to create a set of random agents inside a box, (b) to restrict the agents to this same box while shifting the xyz values of the box. This strategy would show the reaction of a set of agents among themselves while being confined to a certain volume. A function that draws the movement of each agent was used to better understand how that specific set of agents with a specific set of rules behave during the experience.

This was a simulation with no scale. The purpose was to study the system itself allowing reactions flows and the behavior of agents between themselves and the environment to be perceived. The way this system performs allows us to work in various scales and create or own conditions for each simulation. It is always important to have in mind that each simulation is abstract and must be translated so it can have some interpretation. The same goes with its scale. One must fine-tune each of the variables for each test to get the best results. Figure 10.3 refers to simulated flux in a square in Porto (Praça da Batalha) and its ramifications. This is a flux representation of a series of agents roaming around the accessible areas of the square and the streets around it. Some areas were more accessible than others were. These results are always relative in terms of scale, the rules that are being implemented, and the adjustments of the variables.

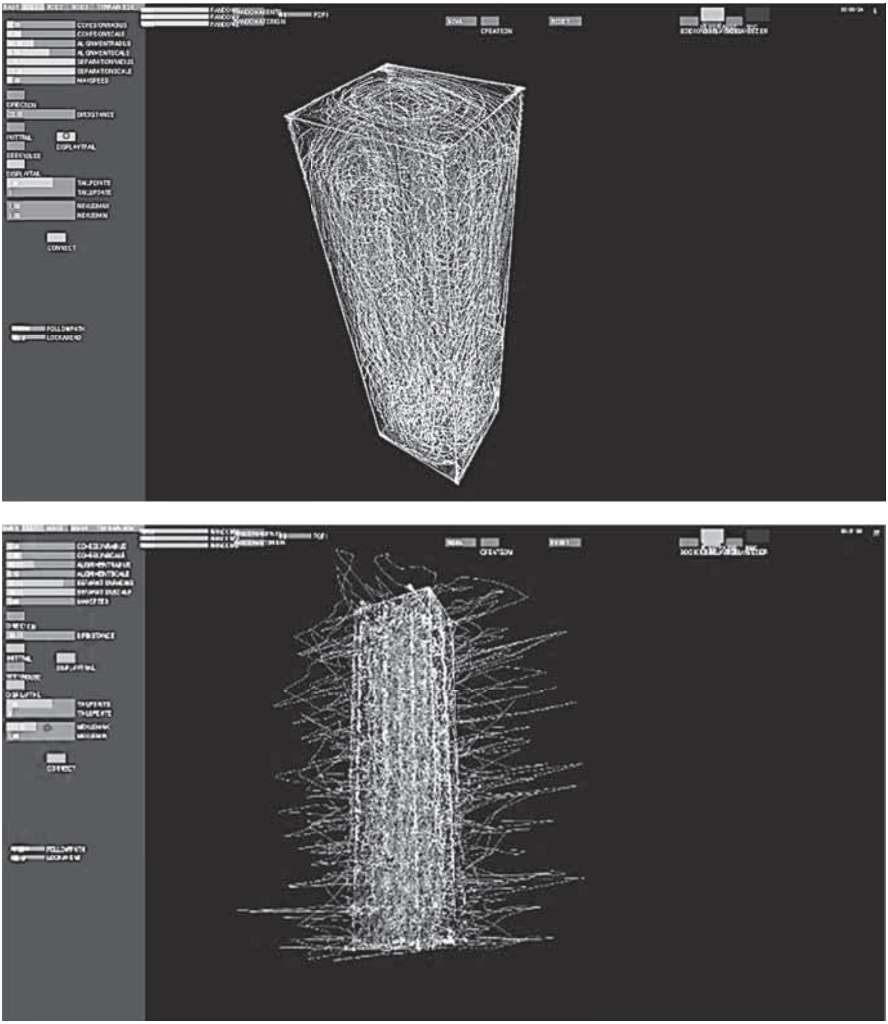

Figure 10.2
Agents' behavior inside a box.

Figure 10.3
Pedestrian street movements' simulation within Praça da Batalha area, in the city of Porto.

In the previous simulation, the variables and conditions created were defined to represent pedestrians moving in accessible space. Some areas were more accessible than others were and barriers with different levels of permeability were implemented, like sidewalks and roads.

The next example focuses on acquiring an in depth understanding of how some of the most important components, like barriers with various permeability values, work with different levels of attraction to a specific block. It also lets some functions of proximity become active as well as the path tracing function. This test has no defined scale and it was meant to show how some components act with each other.

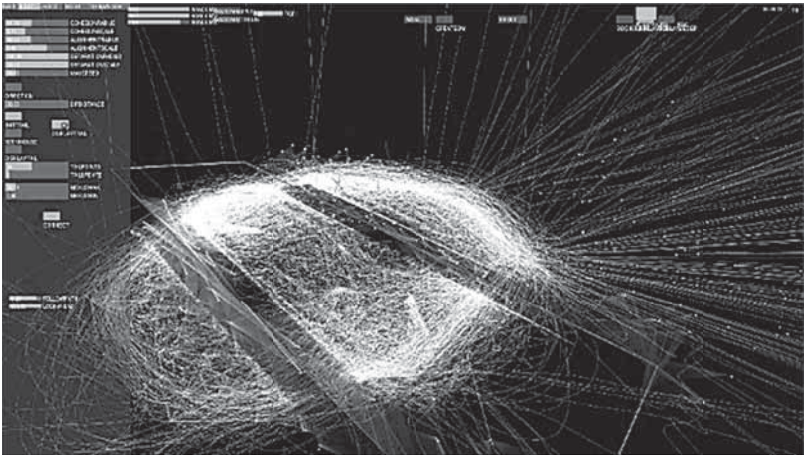

Figure 10.4
Barrier test.

The function construct is applied on the next example and its purpose is to create geometry by layers in z direction. As the simulations goes on, a series of layers connecting agents in range are being created at the same time as their path is being traced creating a self-expanding shape.

In the final step, each layer can be exported as a vector file, like DWG or PDF, for further use in another software.

Figure 10.6 shows an applied example of how the graphic user interface can be used in an urban scale to read intricate relations between different urban areas: Vila Nova de Cerveira (Minho region, North of Portugal) and Goyan (Galiza, Spain)—separated by a river (Rio Minho) and connected by a bridge. Attractors and deflectors were mapped and placed into the interface coordinate system. The correlation between positive and negative places had impact on agents' behaviors.

A function called *followRoads* was implemented to prioritize the paths that had a road connection. Due to the scale factor, there is no differentiation between pedestrians and vehicles.

The strategy later applied was to determine which spot was the most obvious for agents to build another bridge.

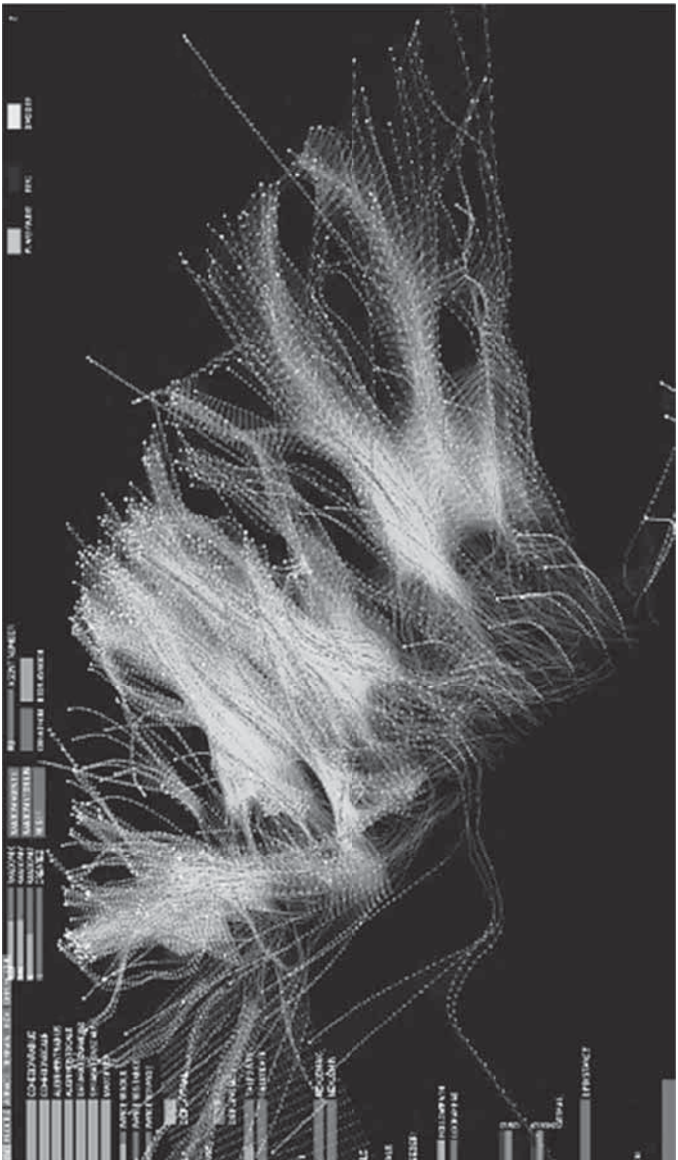

Figure 10.5
Construction by layers.

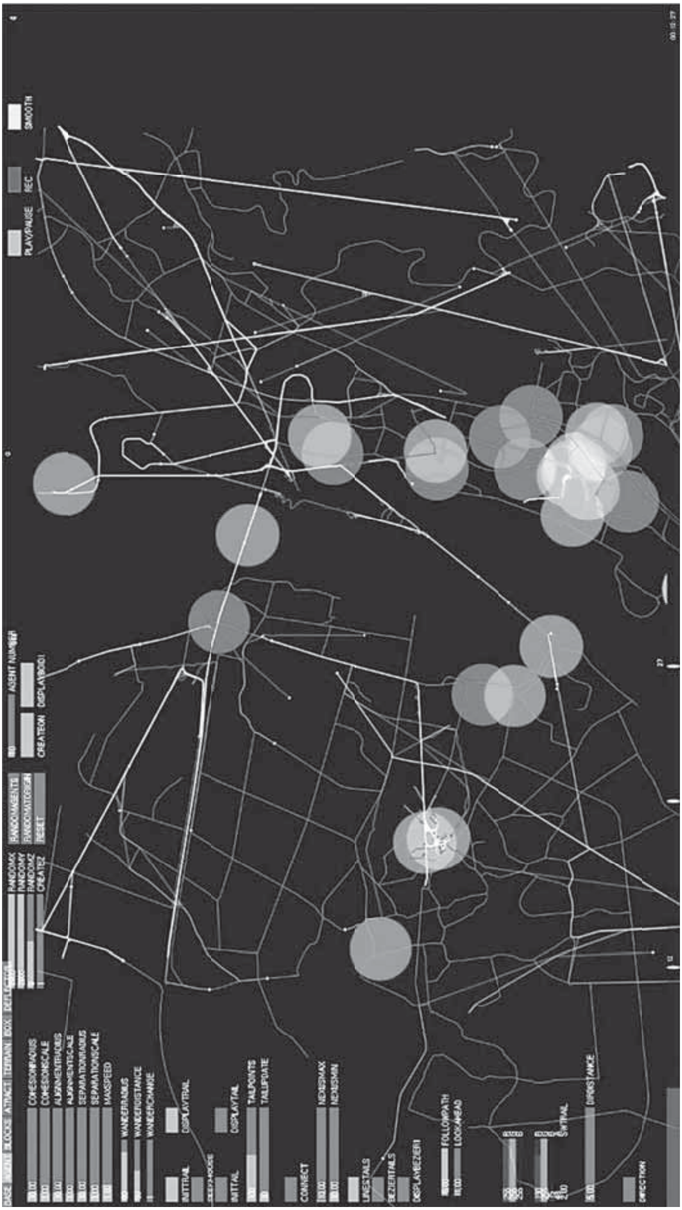

Figure 10.6
Agents reacting to attractors and deflectors in an urban area.

Discussion

This is an ongoing research that aims to narrow the gap between people's dynamics and fluxes within the urban spaces mapped using tracking methods and the simulation between people's movement and space configuration. Modelling digital environments are approaching geometry in a more complex and dynamic way. They evolve in numerous directions as the combination of formal tools of exploration increases and becomes more accessible. The exploration of simulations throughout this chapter intends to demonstrate their potential and to provide a digital tool based on agent-based methods towards movements' simulation in different spaces. Although the possibilities of the agent-based modelling environment and space exploration are relevant in an abstract way, they should always be under interpretation and must be framed within proper semantic context and fine-tuned regarding conceptual and theoretical developments. It is important to bridge this approach with "traditional" space analysis methodologies used in a *real-world* context. Moreover, it is relevant to combine this graphic user environment for agent-based modelling and simulation with *in situ* qualitative approaches. On the other hand, it is also significant to compare the results from the agent-based modelling and simulation with other types of formal methods, like configurational analysis based on techniques derived from space syntax.

Notes

1. Patrik Schumacher, "The autopoiesis of architecture," (v1), *A new framework for architecture* (2010), http://www.patrikschumacher.com/Texts.
2. Schumacher, "The autopoiesis of architecture."
3. Daniel Shiffman, "The nature of code," in *Simulating natural systems with processing* (self-published, 2012), 260-1.
4. Craig Reynolds, "Steering behaviours for autonomous characters," *Game Developers Conference* (1999).
5. Shiffman, "The nature of code," 260-1.
6. Reynolds, "Steering behaviours for autonomous characters."
7. Reynolds, "Steering behaviours for autonomous characters."
8. Reynolds, "Steering behaviours for autonomous characters."
9. Reynolds, "Steering behaviours for autonomous characters."

Chapter Eleven

Locative Media Art in Urban Space's Analysis

Isabel Cristina Carvalho

Introduction

The rapid transformation and technological innovation, alongside easy access to information in real time and to multi-functional mobile communication devices—associated with the growing concentration of population in urban spaces—results in a new urban paradigm defying social conditions set in the emergence of new ways of space appropriation and urban cultures.

Current mobile technology, combined with digital convergence, produces mobile unfolded communication that enables the expansion of connection modalities between man/man, man/machine, and machine/machine. Computational ubiquity allows a speed of information transmission never seen before, referred by Lemos as "extended mobility,"[1] shaping current society to an information society, which Castells defines as a "networked society."[2] New technologies promote and encourage a participatory culture (referred to by Jenkins) and new processes of citizenship's engagement.[3] Mass media communication, as well as the process of emission-reception of information, also changes. The user is no longer a passive spectator—he now has the possibility to be an author and actively participate in the generation of contents (blogs, forums, artistic performances, among others). However, in our days, the concept of mobility joins public participation to this. New technologies (tablets, smartphones, etc.) allow access and communication at any time, to and from any place. Without geographical barriers, the permanent interaction between people and between spaces is encouraged in a constant connection between real and virtual.

The notion of space and time “expands:” one can access or produce real-time information anywhere, always “in touch” or connected in the “timeless time” of Castells,[4] or in the “instantaneous time” of Nowotny.[5] All this concentrated in a small technological device. Technological progress has altered the relationship between man and the world in only a few years; time and space–related concepts have been changing and adapting. The urban "organisms" have become more complex. We are witnessing an informational era in which research on computer systems are in constant development and create new paths to go through.

In urban spaces analyses, digital media art enables the displaying of the artistic development of our cities. Thus, it enables and triggers new experiences and multi-sensorial perception, encouraging and facilitating public participation and social interactions, as well as establishing new modes of apprehension and understanding of space and urban culture. It sets new challenges and brings questions to the practice of urban design. Urban spaces analyses, grounded in locative media art, provide a wide range of research that goes beyond the physical structure. It is necessary to analyze, evaluate, and develop the relations that take place there, as well as to unveil the “unnoticed” and "invisible" that "builds" the identity of a place and its "collective memory."

Urban Spaces, Dynamics, and Flows

Concepts about time and space have been changing and adapting themselves to artistic languages that have been influencing new ways of being, expressions, and relationships. The information era, built through the media, in constant development, is referred to by Santos as a technical-scientific-informational period, in which the speed and fluidity of information make the concept of distance relative.[6]

Network technology facilitates the permanent connection to several places, fostering mobility and the immediacy of the globalized information, and determining a changing perception of space and time. It overcomes geographical and cultural frontiers (multiculturalism). New practices of social mobilization arise generating a synergy between virtual and physical spaces, questioning established concepts: private and public, space and time, dematerialization of place and distance.

> *Today the public space is most present on the internet. Through blogs, social networking sites and other online tools, people exchange ideas and public opinions are formulated. The contemporary city has moved into virtual space.*

> (…) *At the same time where the private has become public, the public space is used as a private space. Electronic devices like mobile phones, GPS and other tracking devices personalize and privatize the public space.*[7]

Within this *continuum* of information, Castells refers to as a "space of flows."[8] He perceives it as a new space where social practices are dominant and shape the networked society, consequently affecting forms of socialization. Through the merge of place and space of flows arises the digital information territory—hybridized, with Internet spots enabling access to places' information as well as spaces' flows. Contemporary urban places, ruled by science, technology, and information, become not only flexible but also new communicative spaces, designated as "digital places" by Horan,[9] such as current day *agoras* or urban places permanently connected.

The convergence of digital technologies with telematics networks in the current Information Society rewrites the definition of urban spaces. The user's immersion is no longer required in a virtual reality. We are living in the "always connected" era. An era in which computational machines are included in our daily lives, with a trait of ubiquity. The user no longer needs to move to a network access point as these are now part of his own environment. These "always connected" environments, constantly integrating more and more information, generate new data available to be consumed.

Informational Territories, Computational Ubiquity

Urban spaces enable functions and interactions. Nevertheless, the focus should not remain in the physical structure of the city; one should also take into account the information exchanges and relations generated in them. The correlation between urban spaces, electronic environments, and social mobility characterize what Souza e Silva classified as "hybrid spaces."[10] Santaella refers to them as "interstitial spaces,"[11] and Lemos considers them "informational territories."[12] In addition to the physical, cultural, and social features, urban spaces also generate information.

New digital technologies, communications networks, and current information societies rewrite urban spaces. It is necessary to take into account the interaction between places and flows, synergies, and connections allowing connectivity between physical and virtual realities.[13] The question of temporality in urban interventions is getting more attention than ever before.

Mehrotra, in his exhibition "Urban Landscapes—Indian Case Studies: The Kinetic City,"[14] recognizes the importance of a creative compromise between the static city and the dynamic city of fluxes, and develops the idea of a "kinetic city" as an obvious response and a necessary tool for temporal interventions. The core concept is to facilitate new readings, conceptual programs, and ways of interaction. Opposed to the static city, the "Kinetic City" is the element that shapes and reshapes urban spaces. Mehrotra also reflects on the need for a more flexible use of the city to allow different interactions between the physical and the virtual, the formal and the informal, the planned and the self-organized. Resulting from technological development (especially informational and communicational) there is a dilution of boundaries between real and virtual urban spaces paving the way to the global village coined by McLuhan.[15] Hence, urban spaces analyses must include new parameters, namely, the level of connectivity, the capacity for sensorial experimentation, as well as the digital production level, creativity stimulus, and intrinsic knowledge, among others.

New technologies (and inherent ubiquity) encourage and facilitate a participatory culture important for the exercise of citizenship.[16] The process of emission-reception of information also undergoes changes. One has the autonomy to create and send real-time information freely, alone or in a network, collaborating with other users, within vast networks of information. Videos and images are being increasingly shared, a phenomenon pushed by the use of mobile phones and personal camcorders in depicting and documenting everyday life.

More than the technological advancement and its potential is the cultural process involved—citizens are now able to express their views, opinions, and interpretations, to intervene and to practice active citizenship. Thus, arises the communication mediated by networked computers that Santaella refers to as "cyberculture,"[17] and Lemos explores as a sociocultural form that emerges from the symbiotic relationship between society, culture, and the new digital technologies of communication giving birth to new social forms.[18] In this new context, Lévy points to the formation of a ubiquitous "collective intelligence,"[19] in which nobody knows all but the media convergence allows for the restructuring of the available information, so people can compare data, make decisions together, and produce new knowledge. This "collective intelligence" relates to a virtual community, in which a wide participation is possible, as well as discussion and exchange of information.

Locative Media Art and Interactive Space Narratives

In recent years, there have been artistic interventions because of transdisciplinary research. These explore social and cultural uses in urban places through the application of mobile technologies and experimental platforms that allow people to access content such as text, audio, and pictures as agents. Additionally, these encourage ownership of space and urban revitalization by individual immersion and public participation, contributing with mappings of temporal, cultural, and spatial geo-referenced experiences, to increment a "collective memory" as a socially shared notion, allowing the reconstruction of the past experience in the present.[20]

The artistic interventions explore and encourage the use, perception, and apprehension of urban spaces, showing a new relationship between media, urban spaces, and cyberspace using digital media art, exploring mobile technology and location awareness, promoting and exploiting collaborative mappings, leading to the valuing of the place and the physical informational mobility. They also seek to awaken sensations and emotions and create new opportunities for production of a sense of those places. These interventions, due to their acting performance, promote and facilitate the active participation of the population and stimulate social engagement within urban spaces through "*shared and multisensory experiences and collaborative productions.*"[21]

New technologies contribute to the development of exploratory opportunities and are becoming determinant factors in perception and artistic representation, providing renewed ways of experiencing art in urban spaces.

In 2002, the artists Esther Polak and Kee Jeroen, in the installation "Amsterdam Real Time,"[22] with GPS technology, demonstrated that each person had their urban mental map of the city.

In 2003, Karlis Kalnins became co-founder of "Locative Media Lab," an institution dedicated to this kind of research. Kalnins links the mobility perspective to technological resources relating them to location, referring to the process as what he defines as "Locative Media." Lemos defines them as technologies and location based services, which enable the appropriation of urban space from notes with informational content, whether written, visual information, and/or oral.[23]

Christian Nold explores the concept of "Emotional Cartography" and uses the logic of a participative culture, observed by Jenkins,[24] to connect art and urban daily lives, through interactive, subjective, and emotional interventions. In the search for a subjective cartography of space, the artist uses the city as the scenario and, with a sensor and a GPS, investigates the relationship between the urban space and the emotions created by it, providing “maps of emotions” experienced on an individual and collective level in a given space. Subsequently, that information is compiled in charts that indicate the level of emotional intensity in each particular location. In an interactive environment, information is not only transmitted/received, but also perceived/felt. Taking this into account, the concept of art expands to a “dynamic system” providing different experiences and results according to the person who experiences it. The stimulation of the senses is consolidated with an “immersion” in the artwork, implying that this is most of the times an open and “unfinished” process.

Locative media art uses mobile devices equipped with GPS. It uses technology and contextualized information, connecting the physical space with digital information, thus allowing the “user” to read the environment. It is a hybrid space both physical and digital built of connections. It creates and recreates new perception experiences and experimentation, working as a regenerating factor and encouraging the use of urban spaces while becoming, at the same time, a working tool in the analysis of urban spaces. Mobile and Internet technologies allow virtual annotations of the city, indexed with data location (latitude and longitude), consequently strengthening the sense of belonging and identification with a specific urban space. Such is evident in these interventions: “Yellow Arrow Overview,”[25] “Urban Tapestries,”[26] “Mobvis,”[27] among others. These technological interfaces encourage and provide interaction between the physical, social, and digital networks. They integrate the virtual in the real space through sensory perception while involving the public in participatory performances, positioning themselves in the visual arts, performing, and scenic arts world.

In 2011, the project “aQi”[28] emerged, which targeted the question of the connection between physical space and the virtual information—the interface warns the user about the proximity of a geo-location, providing access to that same information and giving the possibility to intervene and interact. These new social and cultural relations bring their inherent problems of ownership and evolution within urban spaces, in real time, creating new narratives, new interactive ways to relate, new readings and languages in urban spaces.

In his project "34 north 118 west,"[29] Hight[30] discusses the concept of "locative spatial narrative." He argues (in *Narrative archaeology*) that the concept of location should be experienced. The association of locative narrative with augmented physical locations and digital information will allow the places to be "read." The development of urban narratives supported by augmented reality technology enables the transposition of information from virtual to physical space in real time, thus expanding the relationship with the place, providing new readings between real and virtual space interactions and new media experiences from the urban environment, giving place to a "collective memory."

The information (virtual data) becomes integrated in the physical space; for example, through a QR Code, one can access and view these flows of information, namely stories and local narratives, movies, pictures and videos, related to the space or building concerned. Urban interactive narratives enable questioning, experiencing, and understanding of how media and technology convergence affects the experiencing and apprehension of urban spaces *in loco*, taking into account that the "cultural processes by which we manage and understand spatial practice are in turn embedded in the technological products that we bring into those spaces and use to support those practices."[31]

The project "Wikinarua"[32] is a partnership between Federal University of Brasília, Federal University of Goiás, and Federal University of Piauí. It focuses on the use of mobile technologies and urban augmented reality, and explores the concept of connection between social networks that interact with each other and enable the process of media sharing, such as photos (Flickr), videos (YouTube), music (MySpace), among others. Hence, each user may produce and experience geo-referenced narratives. This personal annotation in a specific location narrative, in addition to revealing hidden stories, allows immersion, insertion, and embedment of social knowledge thus generating new forms of relationships between urban spaces and people that need to be approached in socioespacial and cultural, digitally unfolded dimensions.

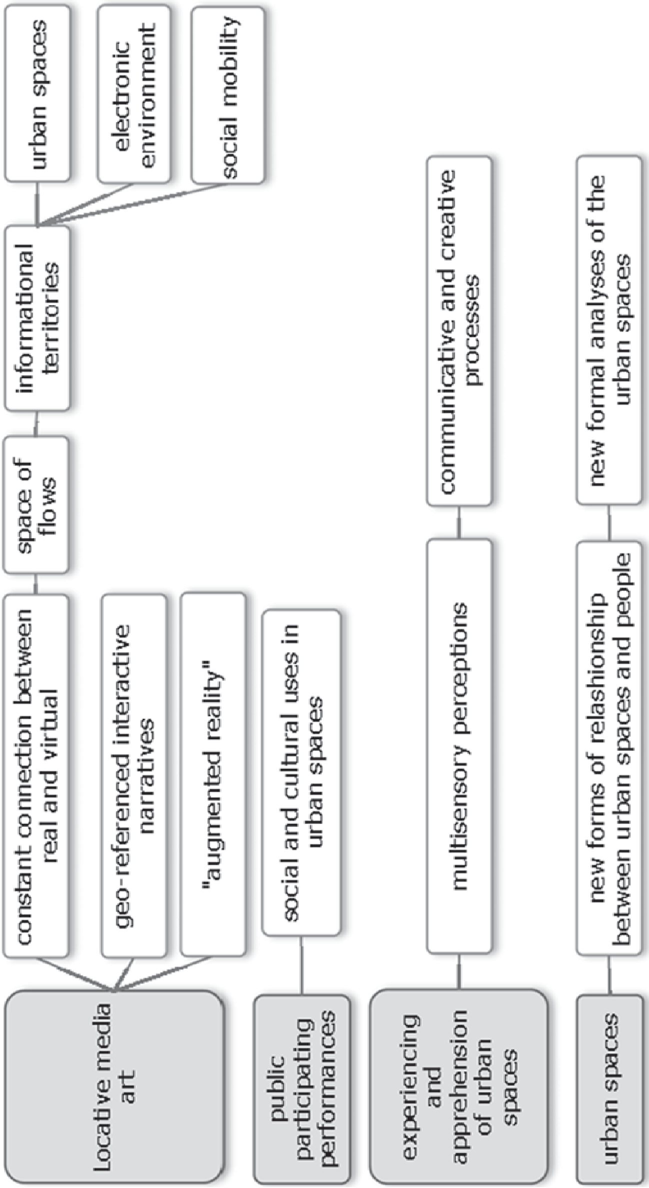

Figure 11.1
Diagram of the correlation between locative media art and urban spaces analyses.

Discussion

Advances on multi-functionality mobile communications allow us to access or produce real-time information anywhere and interact with digital informational territory. Within socially constructed urban spaces associated to digital media art, one can find great potential in terms of multi-sensorial perceptions and experiences, by encouraging public e-participation, facilitating social interactions, and promoting dynamics into urban spaces. The contextualization of information *in loco* (where it is experienced), through urban interactive narratives, allows the exploitation of informational territories. The information is contextualized, and can be displayed and expanded by other users, adding knowledge, cultural, and creative significance.

Urban interactive narratives can be perceived as tools of a communicative and creative process to enrich urban spaces. An important contribution to unfold interactions within the urban spaces is to encourage and promote public e-participation in its co-design. To do so, it is important to integrate locative media art into urban spaces analyses. The knowledge achieved through several case studies concerning locative media art demonstrates the increasingly potential of intuitive interfaces combined with formal methods in urban spaces analyses, exploring the notion of ubiquitous computing to a level where the transposition of spatiality's constrains occurs without our awareness of it.

Information Society demands new paradigms, which, due to their recent matrix, still raise some doubts and criticism. It is therefore necessary to study the relationships between places and spaces (physical and virtual), including the communication established on and by them through locative media processes. Most importantly, there must be constant questioning in trying to understand issues concerning flows in urban spaces and ubiquity in digital technology (Internet, GPS, and mobile applications), taking advantage of data's constant growth in order to collaboratively analyze and to co-create urban spaces.

Notes

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CHAPTER TWELVE

IDENTIFYING CASA DA MÚSICA' SPACE INTENSITIES PATTERNS

ANTÓN TEJADA, DAVID LEITE VIANA AND LÍGIA NUNES

Introduction

The notion of *outside space* (defined by M. Foucault) and the philosophy of *becoming* (elaborated by G. Deleuze) set the research, initial framework, seeking to analyze the capacity of a highly dynamic space, such as the surrounding of Casa da Música (2005), in the city of Porto (Portugal), to generate a place-phenomena, specifically, the subjective construction of an urban "place." Such a concept owes its roots to the cognitive creation by all citizens that walk and apprehend a space. This makes it a complex phenomenon (non-linear) because it cannot be defined from the dissection of the cognitive units that constitute a "place." Within daily pedestrian fluxes along the area of Boavista (Porto), immediate surroundings of Casa da Musica, this specific area represents an exceptionality in terms of urban space, characterized by a minimum of program and a maximum of action, which is the reason why the research focuses on this spot of the city.

The work tends to approach this space from the analysis of the current reality, through videos, capturing pedestrian fluxes in different months of the year thanks to the use of a biometric library, called OpenCV, that recognizes individuals moving along the square. Afterwards, the research seeks to explore the relationship between pedestrian performances and this space using the theories of Deleuze & Guattari,[1] which create a grammatical field from where to understand the data pulled out from the OpenCv methodology. This phase is accompanied by the generation of different types of visualization of that data, each of them orientated to get a particular reading according to the theory. This approach tries to re-tackle the notion of "place" in such a dynamic urban space as Casa da Música.

Theoretical Approach

Darmstadt, Bauen Wohnem Denken Conference

We owe to Martin Heidegger, particularly to the conference (Building, Dwelling, and Thinking), the symbolic birth of the contemporary concept of *place*. According to Heidegger, this notion has a clear relation with dwelling but the spatial conception of the modern city forgot the real meaning of dwelling. Therefore, Heidegger's understanding of space, later assumed by Schulz and his "genius loci," was a fundamental vision to give a response to the modernist spatial think of the first decades of the 20th century. In this conception, the German philosopher put at the center of his theories, the "dasein" (being-in-the-world) to which he imagined an inherent space to inhabit, the *heimat*. This vision was right to address the existential space (an inside that all of us inhabit) and the domestic environment (the place where we live when we are children and keep for the rest of our days inside our memory) to sum up the space that leaves traces on us, and where we recognize ourselves inside, our home. But when it is faced with an urban space, in a context of "supermodernity,"[2] this theory looks expired, as defends Neal Leach, who points out that because of growing nomadic societies, the spatial identification has materialized new shapes.[3] From this point of view, it is inevitable to question: What is the *genius loci* of a massive city? Does just a single *genius loci* exist? Does only one true *genius loci* exist?

Marc Augé

—Non-Places. Introduction à une anthropologie de la surmodernité—

These questions highlight that when the subject approaches the urban territory, he realizes that is not as simple to reinforce a specific genius loci in highly complex environments with the ontological formula valid until then. This seems to be a shared point of view held by thinkers such as Marc Augé, who, in the 1990's, pointed out new spatial typologies that were composing our highly dynamic urban landscapes. This meant the emergence of a new type of space, "the opposite," regarding the sociological concept of place: "associated with the culture localized in time and space."[4] In this work, Augé reflects a concern about a new era, the "Supermodernity,"[5] pointing out the proliferation of new ways of occupying space. In this way, he brings up, in a protagonist way, the concept that comes from the French sociologist Michel de Certeau: "Non-places."

> *If a place can be defined as relational, historical and concerned with identity, then a space which cannot be defined as relational, or historical, or concerned with identity will be a non-place.*[6]

The fact is that new metropolises have just fallen in a rough indeterminacy of the "generic."[7] From which, arises the alarm that the globalization could end up with places. Nevertheless, the essentialist answer to this virtual threat had considered that the opposition between non-place and place can occupy the whole spectrum of the problem, when is precisely the concept of space, which does not find place in this narrow dogmatic framework.[8] The result of this "mutilation" is the thought that non-places should be replaced, occupying everything with places, "filling up the world with meanings and icons."[9]

Even though, Augé falls in a reductionist field of antagonisms and "dichotomies."[10] His concept of Supermodernity is useful to warn about the current global context, in which space has achieved new shapes.

> *The Supermodernity space has not the exact measures of the one we've been living, since we live in an era that we have not learned to see yet. We have to rethink the space.*[11]

Michel Foucault

—*Of Other Spaces. Utopias and Heterotopias*—

That space that we did not learn to look at yet is the "outside space,"[12] that Foucault tried to address decades ago, focusing on those types of spaces that are strangely engaged with all the others, in a way that suspends, or inverts the ensemble of relations. These kind of spaces received the name of *heterotopies*. All these reflections came up from a conference in "Cercle des études architecturals," as follows:

> *The descriptions of phenomenologists* (...) *primarily concern internal space. I should like to speak now of outside space. The space in which we live, which draws us out of ourselves* (...) *is also, in itself, a heterogeneous space.*[13]

Certainly, the phenomenological conception focused its efforts on an inside space where the subject occupies the center of the board. However, such postulates seem to be inexactly facing a "Supermodernity" environment where the classical ontologies began to waver.[14]

Years later, Michel Foucault completed his work "Discipline and Punish,"[15] in which he analyzed, among many other issues, the strong presence of a power network in the Panothicon by Jeremy Bethman. This approach to space caused a revolution in the interpretation of it. With this outlook of how power expands through stable networks, we are faced with a new model of space that reveals the strong relation between the localized space and the networks. The subjectivity of man ceases to occupy the center of the board, and new approaches of places emerge.[16] That point of view defines the starting point for a revolutionary group of geographers who defended the existence of new spatial entities, the power networks. With it, they brought up a new approach focusing in network relations composed by the social as well as the material: The Actor-Network Theories. Bruno Latour is one of the most important investigators of this theory, a French sociologist who analyses the spatial mechanisms that Louis Pasteur developed to materialize a stable network (*singularity*) in which the domination center is placed. After some decades, a revision of this theory appeared due to the recognition of an *Imperialistic behavior by the networks.*[17]

Lee Brown and Paul Stenner mentioned that as phenomenologist felt in the anthropocentrism excess of considering subjectivity isolated inside, relational geographers had launched subjectivity out of the board in a precipitate way. Giving a response to these critics, a second group of geographers adapt the post-structuralism postulates to a redefinition of actor-network theories. An example of this is the work by the French sociologist John Law, who supports the idea that space should not be understood as a "container,"[18] but as network meanings: a creation in which all the subjectivities of objects participate. Law, in collaboration with Annemarie Mol, sketches a new type of space, called "fluid space."[19] In a network, the relations between actors, entities, and objects are clearly defined. In a *fluid space*, such clear definition does not exist and there aren't obligatory points of passage, nor centers of domination (e.g. Panopthicon). Instead, these spaces are the result of "viscous combinations" in which several elements interact in a continuous process of "becoming."[20] This meant a big change in the theories of space, because the focus moved from this or that subject towards a *becoming*, understanding this concept as the transformation of the basic units of reality, the assemblages. Then, the space is seen as an "undulating landscape of network relations in which differing spatial contacts coexist."[21] The description of a high complex space as a combination of diverse heterogeneous materials, which means that they are composed of different spatial practices of identification and forms of membership. Space is, then, a mutable entity instead of a defined one.

Gilles Delleuze & Felix Guattari

– Thousand Plateaus –

The geographers, mentioned in previous sections of this chapter, followed the ideas from Gilles Deleuze, according to whom we should leave a topographical notion of space linked to Euclidean space, going toward a "topological conception of space"[22] approach that refers to how objects are formed or displaced by the networks. At the end, is assumed that networks generate their own space-time configurations. Consequently, the landscape is folded, wrinkled, and fractioned by networks with non-metrical proximities. Such topological conception, owes its roots to mathematical principles from Gauss, and the philosophy of *becoming* from Gilles Deleuze. According to Manuel Delanda, this *becoming* is a continuous process of change, and emerges from the ontology of dynamic. Then, the space should face the shift of the subject, from a fixed entity, towards a *becoming*, based on a continuous transformation ("Orchid and The Wasp") between disparate elements.

> *The work of Gilles Deleuze develops a way of conceiving reality in terms of dynamic process that privileges difference rather than identity, movement rather than stasis* (...) *The nomadic subject experiences and thinks space and time in terms of blocks of space-time that are not necessarily linked into rational whole of measurable units*.[23]

In this "deleuzian caosmology," the subject is decentered (that is why he critics the psychoanalyzm: it is not about competence, it is about performance), so the attention moves from this or that subject towards the lines that pierce the subjects in becoming. What is driving Gilles Deleuze to assert the notion of place? According to Deleuze & Guattari (1987), there is a *de facto* different conception about space between two key-concepts: Smooth and Striated. While on the *smooth* space, the line subordinates the points (directional move); on the striated, to the contrary, the point subordinates the line (dimensional move). As Dovey declares, "these two notions are two conceptual tools from where to think the space." What is relevant for the analysis is the nature of both. While the *smooth* refers to the space of intensities; the striated is related to extensities. This distinction is one of the main "twofold binaries" that compose the thoughts of *Thousand Plateaus* (tree-rhizome, state-war machine, molar-molecular… and so on), and let this study drive the data that could be extracted from the recognition of pedestrian fluxes. Because such distinction highlights the space where any becoming is made, the space of "local operations."[24]

Smooth space is filled by events or haecceities, far more than by formed and perceived things. It is a space of affects, more than one of properties. It is haptic rather than optical perception. Whereas in striated forms organize a matter, in the smooth materials signal forces and serve as symptoms for them.[25]

The intensities carried by lines that flow through the space look responsible for what Metzger, recovering the thought of Karen Barad, calls phenomenon. As Metzger (2015) defends:

The proposition that I wish to offer is that we do not approach place as either a subjective or objective entity, but rather as a relation that enacts both subjects and objects, what Karen Barad—drawing on Niels Bohr—dubs a phenomenon, or what Michel Serres calls a quasi-object.[26]

However, how could we register those intensities on a specific space? In addition, what specific spaces are precious to undertake such approach?

—Where and When—

Before answering the first question, is important to grasp the second one, presenting the object of the study, which is seen as a space where to test all these "deleuzian" theories related with space. For such purpose, the choice is the "famous" building by OMA—Casa da Música: a public equipment conceived between 2001 and 2005 as a result of the celebration of the event "Porto—European capital of Culture."

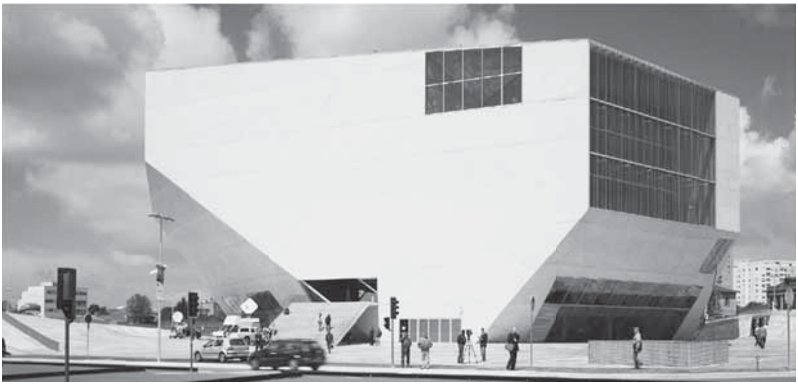

Figure 12.1
Exterior of the Casa da Música

One of the potentialities that were reinforced in such an event was the culture, and the materialization was about build a new icon for the growing city of Porto. Taking as paradigm the success of the Guggenheim Museum in Bilbao. In this case, a Hall of Music, instead of a museum, called Casa da Música. That equipment would consolidate the Boavista zone as one of the future main centers in the city. A fact that municipal governors had been looking for since the 1970's and 1980's. This zone is characterized by residential and commercial areas and, more importantly, it is one of the most relevant transit nodes in the city, with main roads, bus stops, and metro-bus interface. Then, the intervention would reinforce this zone as a centrality to all kind of entities. For local people, who would feel glad "having" a global building; and commercial entities that would multiply the number of private equipment, situated close enough to get a publicity impact. Regarding this new building that became an important symbol of Porto, it has to be clarified that the focus of the work is on the space that surrounds the building, specifically, the smooth square designed as well by OMA where it has inscribed the music hall piece. This space, well known by the strong dynamism of its condition, provokes that the public space in Casa da Música is being affected constantly by fluxes, dynamics, and constant flows. In fact, it is seen how the design of the public space stimulates movement, breaking radically with the established urban plan proposing a topological space in which preconceived functionality is not present anymore, making a wider mobility of all the participant entities in the area easier, with a travertine marble floor that makes this place a main skate center in the city.

Figure 12.2
Aerial View of the Casa da Música

The square is presented as an antithesis to any kind of spatial typologies surrounding it, pointing to a new paradigm of space—that one diagrammatic space that sets the global character to the area. One of the consequences of this event is the relocation of relative local zones, new spaces appearing where national and international networks operate. This means that new agents invade such space: tourist, companies, and new generations. However, who conceived the Casa da Music, and for what purpose? To try to grasp such a question, it is relevant to comprehend who conceived this square and how he did it, to have a better understanding about the surrounding space of Casa da Música.

—Who—

In 1999, after Porto was named "European Culture Capital" for 2001, a competition was launched to design a new concert hall in the city. OMA was invited to participate in a competition for the construction of such music hall, for the city of Porto, being later the winner. Rem Koolhaas lead this studio, a well-known architect who shows a particular interest for the urbanistic dimension of architecture, understanding this activity as part of the infrastructure of urban events. Such infrastructural position enables the operability of the public space, a position that is clear since the beginning, through works as the *Retroactive manifesto*, *Delirious New York*, or his dystopian speculative work *Exodus*. The essay called "Bigness and the problem of large," published in *S, M, L, XL*, reveals sentences like: "Bigness is no longer part of any urban tissue (...) its subtext is f*** context."[27] This sentence puts the author far away from the utopian thought. Mainly because he defends that the Utopia remains suffocated on what "should be," instead of operating with the current forces that operate among supermodernity cities. From Koolhaas point of view:

> *We live on a changing and fluid world, auto-organized, where modern humans almost play on a reticule representative world of abstraction, of rationality and of the most brutal approaches to the nature. As a consequence, the modern architecture does not draw his shape from the topological world of the fluid materiality, but yes from the rigid representative world, of the ideal, of the excessive machinic (naïf). This world is captive, blind to the temporal dimensions, what produces an architecture blind as well.*[28]

The position of Koolhaas could be described as anti-intellectual, looking at his defense and utilization of the mass culture. This is linked with the populism that goes far from the image and gets close to the action.

Koolhaas' spatial conception presented on his essay called "Imagining nothingness," where claims that a contradiction exists between program and architecture; so he defends, "the maximum of program, and a minimum of architecture (…) where there is nothing, everything is possible, where architecture is nothing else is possible."[29] For this author, the architects of this era should design buildings that do not restrict the action, because the movement is what characterizes the current time. This is present at Casa da Música, where the freedom from the heavy conventions, institutional, historical, or even moral, is shown. This condition of freedom motivates the creation of a space understood as a public scenario, where the only urban condition could be an anthropology of social instability. Therefore, the public space of Casa da Música appears to constitute a typology scenario for the social structure. With it, Koolhaas' position seeks for alternatives to cartography of an urban territory, from its more determined relations that lead the production and the organization of physical space, setting up a new identity and local references as overlapping previous ones. The constant geographical redefinition, based on Koolhaas position, brings us the thought that contemporary spatiality has to be understood as a dynamic process. Then, landscape is seen as a "dynamic stage," a shared vision with the spatial vision of Gilles Deleuze and his philosophy of *becoming*. Therefore, performances of population play the most important role here. It is clear that this (locally usually called) "asteroid" (Casa da Música building) could be understood as the main attractor, diminishing prominence to the pedestrian fluxes, but the stage designed by Koolhaas forces the analysis to go further toward the interest of the surrounds that are open to receive constant citizen movements. This is where the fundamental question stated before is brought up: How could we register those intensities on a specific space?

—How—

Generating Data: Such a highly dynamic space is required to grasp movement fluxes, looking to how they are happening. With a special care to the various subjects, the main object of the research are fluxes and continuous occupations in the Casa da Musíca's space. That is why the tool used here is completely related with what happens in the daily life, the everyday movements of people through the square of Casa da Música, understanding this space as a stage where the subjects reveal their behaviors according molar or molecular forces that pierce them. That is why the research gets help from programming to analyze videos, detecting pedestrian movements and assigning points to that motion, in order to acquire a partial map of human behaviors in the space.

The language used is Python and, specifically, a library released by Intel in 1999, called OpenCV. This library allows detection of every pedestrian that is in movement. Several videos are used as a base for an analysis of pedestrian movements inside the square; these trajectories are drawn by points that reveal patterns of motion along this space.

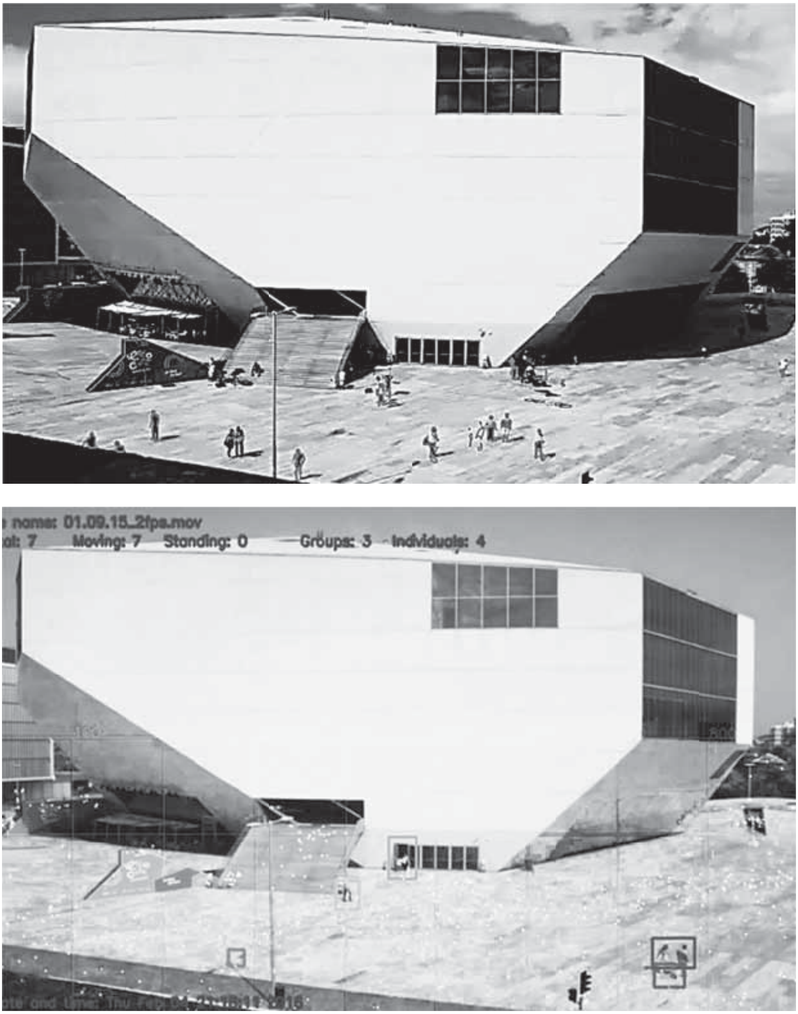

Figure 12.3
Functioning of the OpenCV Library.

The current main use of this library is for security systems and in the industry of "intelligent" cars. In the case of this study, the purpose is the people occupation within space, generating vast documents of data that register the presence of subjects in Casa da Música square. After the program is executed, a .txt is outputted. Nevertheless, the data generated in OpenCV needs a post-production in order to display a data visualization according to the purposes of the analysis, what means express the intensive qualities linked to the square, and the flux of pedestrians.

Data Visualization: If one follows the theories of Delanda, deeply based on Gilles Deleuze's ontology, the intensities could be understood as forces that push the subjects to the apprehension of a localized space in this or that way (bringing to the analysis the two-fold binaries composed by the "War machine" and the "State"). The difference between the pedestrians could be seen as how strong the presence of flows or segment are respectively:

> *Each individual is pierced by two types of lines at the same time: one molar and other molecular. One always presupposes the other. To sum up, everything is politic, moreover any politic is at the same time micropolitics and macropolitics.*[30]

Then, the maps should reveal the mixture of corporeal performances according to the presence of individual intensities. This would be a synonymous display of intensive flows localized in the surrounding square of Casa da Música. As Delanda describes, the intensive maps are defined in a special way:

> *There are, however, other well-defined spaces which we also inhabit but which are less familiar: these are zones of intensity.* (...) *These other spaces are also bounded but in a different, pressure, gravity, density, tension, connectivity, points defining abrupt transitions in the state of the creatures inhabiting those zones*.[31]

So, what would be the aspects to study, according to the intention to grasp those patterns of movements that are driven by the intensities resulting from place-phenomena?

Figure 12.4
Same social profile pierced by different types of forces.
("*molar*" *vs*. "*molecular*")

Thermic Map: The first factor from where to analyze the tracking of fluxes is the notion of "density," defined by Delanda as an intensive property useful to characterize the difference between locals:

> *The number of people inhabiting any one of these regions is one of their extensive properties. But more important than sheer numbers is the relation of these numbers to the area occupied by the region, that is, the density of people in the region. This is an intensive property that is more useful to characterize the difference between locales, between cities and their surrounding countryside, for example, than their extensive properties.*[32]

This notion allows the study to orientate the data toward a thermic visualization that represents the presence of pedestrians on the different zones in the square.

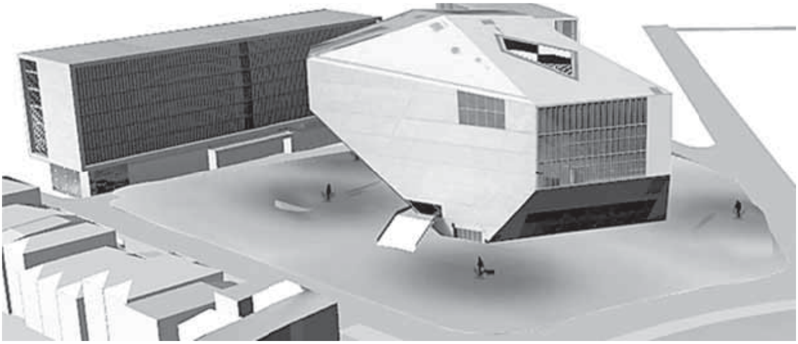

Figure 12.5
Aerial Thermic Map.

Using the plug-in from Rhinoceros, Grasshopper, a gradient of color is applied to the bunch of data extracted from each half an hour video, automatizing the process of conversion from data to thermic visualization.

Figure 12.6
Thermic Maps.

The visualization of all the maps' densities discloses the massive presence of fluxes through the main part of the square, the zero-level area, from where the entrance and the zones that offer less restriction to the pedestrian movements are produced. So, the topological square is characterized by a continuous surface that stays flat in some parts of his limits (allowing to pedestrian to enter) and, in some areas, that connects those entrances to each other.

There are other parts that reinforce the sinuosity of this space, zones elevated from the ground that create an undulating landscape. While the flat zones look messy (almost impossible to grasp a pattern from a pedestrian that is having a sensitive performance with the space), parts of the undulating zones reveal clear moves closer than the others to be formulating the place-phenomena, it means highly connected walks with the localized space that surround the pedestrian.

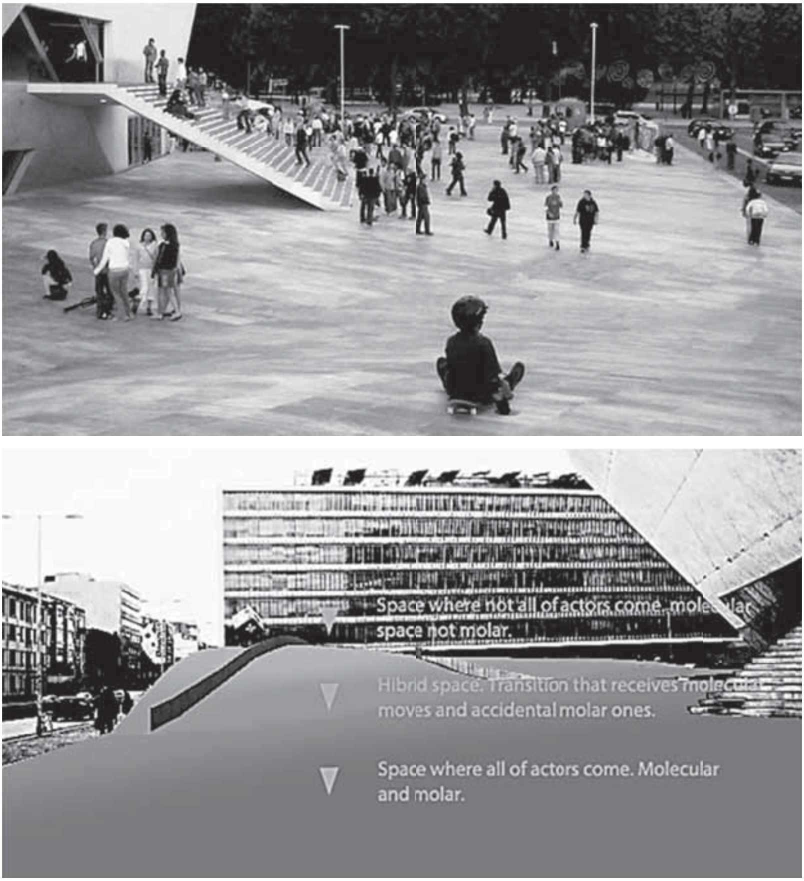

Figure 12.7
Spatial distinction regarding smooth and striated.

Isocurves Maps: Such distinctions push the analysis towards the study of those pedestrian movements that are localized on the undulating zones, fluxes that could reveal an intensive performance resulting from the place-phenomena. So, to detail the thermic maps showed above, the focus is driven to new type of visualization that could let the study reveal new qualities of those tracks that happen on the undulating area.

Figure 12.8
Isocurves Maps.

For these new maps, a new technique has been used, based on isocurves that could connect points with the same value. Therefore, this could say more about those areas that before were simply red or yellow. To do such maps, the plugin from Rhinoceros, Grasshopper, has been used again, which automatically generates these maps from the data displayed before. From these maps, what is relevant more than the chromatic aspect (*occupations*) are the geometries that the isocurves describe (*concentration*). According to this concentration factor, it could be seen which zones are highly occupied, as well as those areas that are occupied by one (concentric geometries) or several individuals (spread geometries). Nevertheless, as was said above, what matters at this point of the analysis is those fluxes registered on the undulating area, where the fluxes are not major but minor. From those movements, emerges a distinction between three patterns according to the activity on the process of apprehension on that space, where the individuals are close to formulating the place-phenomena of Casa da Música. While the first pattern responds to those pedestrians that move to these zones and come back to the highly dynamic areas, the second one is regarding individuals that make a move exploring much more space, probably having a stronger connection with the surrounding space. Finally, the third pattern describes the performance of a pedestrian who changes their movements to stay for long time in a specific point. This third one is recognized to be the closest to formulating the place-phenomena; even though, such assumption is not rigorous enough because of the impossibilities of tracking the internal activity of each individual that involves these actions.

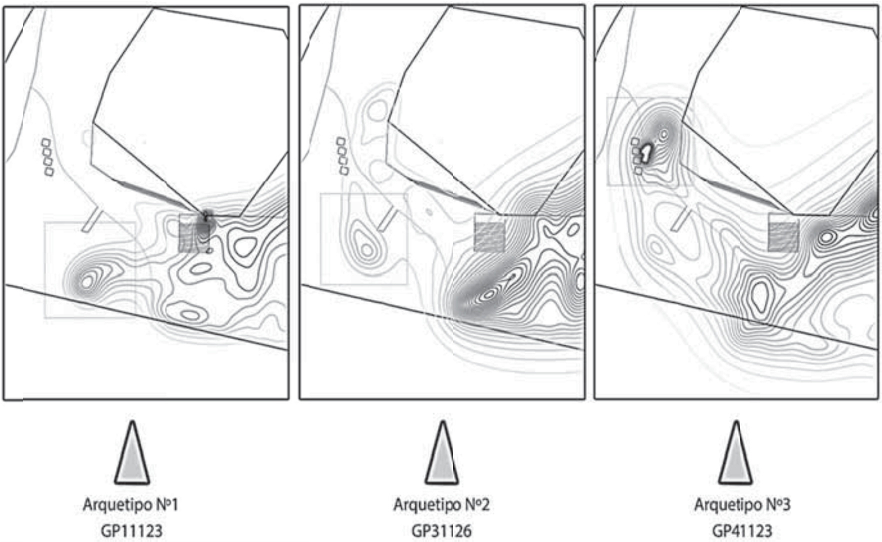

Figure 12.9
Selected Patterns.

Discussion

The analysis closes with the identification of three patterns registered in the undulating surroundings of Casa da Música. These respond to the different presence of intensities that emerge from the subjects who formulate the so-called place-phenomena. With this, ends an approach focused on an urban space that seeks to point toward new perspectives, thanks to the application of emergent technologies with the purpose of responding to the warning set up by Augé in the 1990s—"we live in an era that we have not learned to see yet."[33] This outlook, which tries to face highly dynamic urban landscapes, gives architects and urban planners the chance to see empirically what happens on the urban territory. Therefore, it looks suitable to review this study in future years, reconsidering such malleable concepts. It has also shown a need to incorporate new improvements that the library OpenCV will show, as much as to rewrite the code in order to acquire a better accuracy on the pedestrian recognition.

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12. Foucault, De los espacios otros.
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CHAPTER THIRTEEN

RISKING IT

TELMO CASTRO

Introduction

> *Don't ask me who I am and don't tell me to remain the same: it is a moral of marital status; it rules our roles. Let it free us when one deals with writing.*[1]

In his novel *The Cave*, Saramago mentions that — "Creators have little brains on the tip of their fingers."[2] This subtle testimony, which refers to the importance of the haptic on drawing, is also explained because drawing is, as a methodological, procedural, or project tool, the recognizable support of idea(s), the referential repository of intuition and perception. The meaning of these drawings emerges inseparably in the construction linearly translated into "synopses," bi or three-dimensional, in writings, which support and configure in the mental image truths or lies about the action of drawing or validating. For this reason, the importance of that methodological tool/drawing, its aesthetic manifestation turns it into the fundamental and complex explanation, which incorporates the integrating dynamic of thinking the drawing as *cosa mentale*, giving way to comprehension, transposing the appealing dimension of ambiance, of gesture, of continuous questioning, of plentiful detail, of the surroundings in space, and in the proposed relation with construction.

The integrated and dimensional coverage, where "each drawing is in itself a new element in the perceived and problematized real,"[3] produces transformations in the project and consequently in the drawing, and is echoed sequentially; the before, the now, and the after interpose by overlap or comparison, which result from the evolution of imagination.

In regard to the drawn register as language of clarification, idea, form, and object materialize themselves in transformative elements of the mental imagery in the correspondence between invention and evidence, in the clarification of the drawn object and its disturbed importance.

The drawing responds by approximations, "by which it is capable of being a receptacle for the apprehension and accumulation of numerous knowledges and circumstances of a certain time, images that remain there, until they are present together all the particles capable of being united to form a new composition."[4] This is the evocation of the exploratory purpose of the drawing as an articulated dilation of the thought that Carneiro summarizes, "the subject draws and draws itself in the complexities of the successions of the moments of its feelings and thoughts,"[5] where its uniqueness and consistency come close to the literary process and the construction of knowledge, it is resilience personified in the drawer. The meaning of this resilience transposed to the drawer medium is the physical extension personified by the one who risks it; it is, simultaneously, the discovery of an inner and outer truth, or even, as Zuccaro defined it, "drawing is not matter, it is not body, it is not an accident of some substance, but is idea, order, rule, goal and object of intellect, where understood things are expressed."[6] In fact, they are two separate components in the drawing field: the *disegno interno* and the *disegno externo*. In the conscious and dazzled register, one observes a kind of *forma sine corpore* manifestation. However, as Leonardo had already said, what is incomplete stimulates us to develop it. We can see that the simultaneous action of the processes of coordination, mind, eye, and hand, are inseparable from the stimulus of imagination and the venturing of hypotheses in the organization of chaos, as "confusing things stimulate the mind and new invention"—Leonardo's quote subtly introduces the "haptic" of thought, i.e., the action of the hand transpires an idea and announces something, in the same way as Michaux explains that there is a relationship of cause and effect in all acts of drawing:

> *Do I draw because I see this or that clearly? Not at all quite the opposite. I do it to astonish myself again. And I am delighted if there are traps. I look for surprise*s.[7]

Risking It

It is added that "risking it" is like being by the edge of a precipice, i.e., a condition of fear, just like in the testimony of Mendes:

> *Here is why it is not viable to build* (…) *a railway station in Portuguese manueline style, or a chemistry laboratory in gothic architecture. Both would reveal, not expression, but masks, and architecture is not a Carnival parade. Free drawing has been lost, thus, as a factor of essential importance, in order to imbue architectural work with more rigour*.[8]

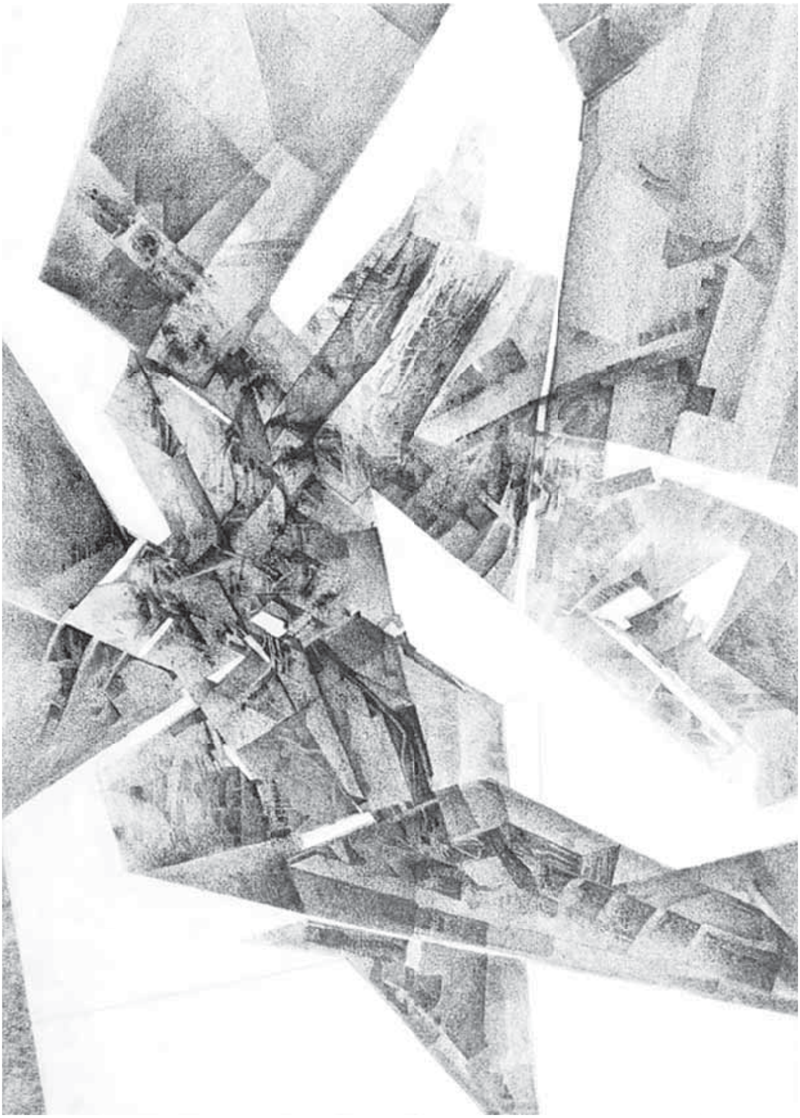

Figure 13.1
“Unfinished cities—012” (2015), by Telmo Castro.

Graphite on paper (45x70cm).

This state of conscience (Figure 13.1) is not an insurmountable hurdle but is the space of opportunity that the drawing constructs—this space of being close of the idea of God, drawing is risking it, giving nature back the ability to renovate and change. A mark, which intervenes in the complexity and interferences of experience. It contains the weaknesses of that drawing, of that act of risking density, of inscribing, planning, of simple desire of representation of the world, establishing a cosmic synchronicity, dimensional and temporal, incorporating and emphasizing the image in the meeting of light in places of shadow, a result in which densities of fine art are added, expressing themselves in "multiple transformation."[9] Kerney states that

> *the same capacity of synthesis marks a primordial unit of sensation and understanding caused by the imagination previous to the functioning of both skills. In fact, the synthesis role of the imagination, which implies both faculties, is so primordial that it operates subconsciously, as if they spoke behind our back*s.[10]

Although, what is possible to be built and recognizable from the basis of similar mental operations done to construct the *perceptuum* of a "body" is where those correspondences take place. The space of drawing lies between the tangible space and the mediating contextualized mark of it. Imagination is, thus, as regurgitation of the relevant traces, of the narrative expression of thought and the use of a continuum without continuity. It is of a transitory character, represented between field/subject/object, unveiling in a way the uniqueness of the discourse of the drawing and its transformation. It is noticeable in Beuys' drawing that the notion of three-dimensionality blurs itself in the diagram planning, where differences of the drawn register are perceived, where the drawing/project expresses its dimension through gesture, in configurations articulated by the line and constructing an imagined presupposition, circumscribed and personal, of what seems brittle, with the delicate representation of the graphic object that comes from the dilemma, the mistakes and schizophrenia of the times, and dissolves cold and rigidity, as we perceived in Beuys' gesture. This *status quo* can be understood to be essential in drawing; "risking it" seeks to express the "energies," establishing analogies with the behavior of creatures and, thus, human behavior. On the other hand, Siza´s drawings are close to the analytical register, in fact,

> *to Siza the gesture of the hand, the movement of the line is crucial to trace the founding idea, give life to shapes and anticipate the action of movement*

through space and time. Dynamic shapes in tension: without them invention might lack vitality.[11]

Discussion

The confrontation mentioned at the end of the previous section, as Curtis (2008)[11] explains, is in a way the construction of a reference, an exaltation of actions and learning processes, highlighting the conscious side of it, always emerging in a willingness, which cannot be clarified instantly, in the truth of the shapes, which inhabit space, and in the matter that also inhabits desire and intelligence.[11] However, how can we define that desire or that "prowess" of intelligence? That unknown space of risking it? Curtis gives one hypothesis. There is an inner circumstance, a choice to find answers to what is not visible, that is not a body, but the will of a body and a mind; but also, what does not have a body as mentioned by Zuccaro[12] is the purpose, the ability to enlarge or reduce things, to readapt the mnemonic sediment of experience.[12] However, using the experimental free field, risking it on drawing at determination of this hypothesis, we found a connection of new stratums or assumptions, combined with the thickness of imagery, a constructive new link to drawing, a stratification associated with cinematic language, a free field from a geographical reference and abstract content, implying a relation (for comfort) to familiar design, a decipherable code, a free reading from their own referential in a context of open work and with constant transformation. At this moment, maybe you can think of others.

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—PART III—

TO DESIGN METHODS OF PROJECT PRODUCTION

CHAPTER FOURTEEN

DATA DRIVEN SIMULATION MODEL FOR HOSPITAL ARCHITECTURE: MODELLING AND SIMULATING CLINICAL PROCESS, ARCHITECTURAL LAYOUT, AND PATIENT LOGISTICS IN A HOSPITAL'S BUILDING INFORMATION MODEL

JOHAN VAN DER ZWART
AND TOR ÅSMUND EVJEN

Introduction

European Society is aging, and this is a burden for healthcare systems in many countries. It is therefore that one large Horizon 2020 theme (Health & Wellbeing) asks for solutions to cope with this aging society. People are getting older, but of the extra time they live people spend more time in sickness. In addition, in most countries healthcare professionals such as nurses and general practitioners are aging, as a group, faster than society itself. This implies that in the coming decades there will be less people in the healthcare sector to do more work. Hospitals become more and more intervention centers in the health status of patients, but still use the largest part of the available financial and human resources. Smart organization and management of healthcare in combination with the architectural design of hospital buildings could contribute to getting more work done in a time with a reducing workforce of healthcare professionals.

Hospitals are a social construct with a high complexity of relations between people (patients and professionals) to perform complicated clinical processes in complexes including a variety of places.

This complexity of people, process, and place makes hospital architecture an exciting context for architectural research and analysis, and also a context in which it is important to learn from previous experiences by Post Occupancy Evaluation of existing hospitals.

> *In order to create a built environment that meets future aspirations, we have to learn by evaluating our existing building stock effectively, otherwise we fail to avoid avoidable mistakes*.[1]

There are some first indications that the use of formal methods in architecture for analyzing hospital architectural floor plans can enhance architectural quality as perceived by patients and employees.[2] Recent literature on Post Occupancy Evaluation (POE) on people's behavior in the built environment, Business Process Modelling (BPM) in hospitals, and Building Information Modelling (BIM) show that the combination of these analytical methods can potentially have a great impact on hospital architecture. However, recent literature also makes the well-known gap visible between "the predicted and actual environmental performances of built infrastructure. Therefore, we need to understand how buildings in use deviate from expectations of their design."[3] Occupant data and building information through the lifecycle of a building can be made visible and analyzed by using a BIM system.[4] Although BIM is often used for the building-in-construction, it has significant value for a hospital-in-use, but the use of BIM as model for organizational planning of clinical processes in a building-in-use is missing in research so far. To link an operationalization of "architectural design" to the use of resources in a clearly defined set of clinical (and/or non-clinical) processes and outcomes, an interdisciplinary approach is required between healthcare sciences, business information modelling, and formal analytical methods in architecture. The aimed result of this chapter is a blueprint for a conceptual framework for the integration of POE and BPM in the BIM of a hospital in order to model both clinical processes and the hospital architecture and measure the impact of the build environment on clinical processes and the interaction between patient and healthcare professional. One approach to model both clinical processes and the built infrastructure would be to decouple the building information from the physical building. "This could enable the building design process to be 'debugged' and or reconfigured 'on the fly.'"[5] These models and analysis techniques can be used to compare clinical processes from different hospitals and test them in different architectural layout options in order to (re)design hospitals and clinical processes that increase both the healthcare professionals' productivity and patients' perception of healthcare quality.

This chapter starts with a brief review of recent literature on POE, BPM, and BIM. These methods are illustrated by three cases on hospital architecture. Next, it is discussed how these methods can be used to combine meta-data of the hospital information system on clinical processes with the measurement of patient and employee logistics and the architectural analysis of the hospital infrastructure. Based on a blueprint for an integration of these methods, this paper concludes with some suggestions for future research on this topic.

Brief Review of Literature on POE, BIM, and BPM

Post Occupancy Evaluation (POE)

Post-occupancy evaluation is a process of systematically evaluating the performance of buildings after they have been built and occupied for some time, with the goal to verify design intentions and analyze the impact on the environment. Therefore, POE is the "examination of the effectiveness for human users of occupied designed environments. Effectiveness includes many ways that physical and organizational factors enhance achievement of personal and institutional goals."[6] POE has the potential to lead to better understanding of how we can complete feedback loops in the building design process.[7] Not the measurement of the physical characteristics of the environment, but the requirements of the occupants is the essence of these studies, measured by the performance of the building from the perspective of its occupants. Current views on POE suggest that it should cover user satisfaction, technical performance, financial performance, and the impact of the built environment on the business or process. Prescribed performance specifications are the starting point for the evaluation and this evaluation mainly relies on two activities:

> *The effective collection of real world data and information and the formulation of this data and information into models that allow trends and deviations to be observed.*[8]

These studies are conducted with methods such as questionnaires, face-to-face interviews, and walk-throughs, but as technology develops the use of intermittent and real-time data also becomes possible.[9] Due to advances in information and network technologies, gathering reliable data for building evaluation becomes easier and "POE changes from one-off practice into continuous information collection."[10]

Preiser states that if POE feedback from occupants can be combined with state-of-the-art knowledge, it is possible to improve building performance; add to the state of the art knowledge, local experience, and contextual factors; and help to generate guidelines and benchmark successful concepts.[11] Vischer called this process "evidence based design," which would establish a new relationship between research and design, basing design decisions on research results.[12]

Building Information Model (BIM)

BIM technologies promise a shared information system to support the orchestration of the information for a building's design, construction, and maintenance. But as BIM system enables users to integrate and reuse building related information and domain knowledge through the lifecycle of a building,[13] these BIM systems could also support the capture of the occupant data as well. However, current BIMs encode mostly the artefacts of the design rather than the reason and motivations for the artefacts and do not at all model the requirements and user data of the occupants.[14] The first step to capture this occupant data is a visualization of aggregated data from POE studies in BIM tools. Göçer, Hua, and Göçer propose therefore a method in which geographic information system (GIS) technologies are used for combining data-collecting and data-presenting.[15] Data captured through POE studies can be used as input data, or transferred to databases and information systems with GIS-based spatial mapping methods. This makes it possible to compare occupant (dis)satisfaction between different locations and time periods, searching for spatial patterns with respect to the floorplan.[16]

Business Process Modelling (BPM)

Perceiving business processes as a unit of work that starts with a set of inputs that are transformed into outputs with value for the stakeholders is straightforward. BPM and enterprise architecture has been used to provide organizations with a model of the information assets of the organization as well the need and purpose of those assets from the perspective of their stakeholders.[17] If the organization's business process information during occupancy of a building could be captured and this information could be provided to architects as occupant typologies, it could help architects to analyze the performance of their own buildings. These occupant typologies could support the development of new designs as well as evaluating previous designs.

To bridge the gap between design intent and operational outcomes, it is necessary to capture, understand and influence building occupant behavior in order to assess and ultimately improve building operational efficiency from a design or operative perspective.[18]

Therefore, the organization's daily business processes and the activities should be detailed, recorded, analyzed, and modelled following a top-down approach.[19] Shen, Shen, and Sun showed how even avatars can be used in a BIM to simulate user movement as a form of pre-occupancy evaluation.[20] Their research focusses on 3D simulations to improve users' understanding of the design, help them to specify their activities in the new architectural layout, and to collect feedback on the design by pre-occupancy evaluation before finalizing the architectural design.

Three Case Examples of Modelling Hospital Infrastructure

Strategic Planning based on Big Data

Inselspital Bern, Switzerland
—Case description based on Walter *et al.* & Schmid *et al.*[21]—

Like many hospitals, the Inselspital in Bern developed evolutionarily in time, which created incremental path dependencies in the physical and organizational layouts. As processual workflows developed faster than the layout of space could be adapted, the optimal configuration of departments, their organizational units, and technical facilities is not always evident. On the other hand, hospitals do collect large amounts of data during their daily operation that also contains implicit information that can be used to reveal these optimal configurations and to improve clinical workflows. If the data is enriched with geographical locations of departments and integrated in a coherent database, it opens up the possibility to have different views and analyses on the organizational system and patient flows. For this purpose, a highly interactive visual analytics application was developed that offers four principal views on the data: (1) the organizational view showing the organizational structure and how the actual medical activities are shaped; (2) the systematic view revealing the operational structure as it emerges from patients moving through the hospital and the way the clinics are related based on these actual flows of patients; (3) the topographical view, showing the actual location of the activities in the built infrastructure; and (4) the chronological view, which adds the dynamic of how events and quantities of patient flows change across time.[22]

The Inselspital used real data from the past to identify existing related clusters of organizational units based on what they were actually doing, and not on where they were placed in the organization chart or building structure. The hospital data contained information on the locations of patients in bed, or in which hospital block exactly s/he was undergoing surgery or any appointment. This made it possible to analyze the patient flows in order to organize the future clinics with minimization of patient transfer distances. These analyses of clinical pathways and patient flows provided a retrospective overview of the big picture of the hospital system in which the hierarchical organizational structure was contrasted with the actual implemented working relationships. As such, differences were revealed between daily clinical processes and the theoretically defined organizational structure, which were taken into consideration when deciding on alterations in the physical infrastructure.[23]

Using Simulations in Various Stages of Hospital Planning

—Case description based on Paju *et al*.[24]—

Paju *et al.* present a framework in which simulation is a part of the whole hospital planning process with estimated patient volumes based on current volumes as the start point for simulations.[25] Different future scenarios can easily be compared in these simulations by scaling up or down these patient volumes. Simulations in the first phase of this framework focus on the connections between different functional units in a schematic layout. In the layout, it is stated which units should be close to each other so that patient and employee processes are fluent. The processes of each unit should be determined in order to do the simulations.

In the second simulation phase, the focus is on individual units and how the patient and employee processes should be in the future. Changes in the processes can drastically improve the patient care by shortening the lead times and improving availability of services.

The focus of the third simulation phase is the movement of the patients and employees inside the unit in order to compare the consequences in walking distances of different layouts drawn by architects. Unnecessary movement should be minimized when designing a functional building. In the fourth phase of simulation, capacity of certain logistic areas, needed equipment, queues, and delays in the process can be determined.

> *Simulations were designed so that the operations inside the ward consisted of daily routines and tasks related to arrival and discharge of the patients. These tasks were different for each employee group. Important rooms* (*e.g. patient rooms, storages, utility rooms, medication room, nursing station and dining area for patients*) *were placed to each of the layouts based on the drawing of the architects. The simulations reported the distances walked by all employee groups.* (…) *Simulation was also used to determine the effects of decentralized storage in comparison to centralized storage.* (…) *People logistics simulation helped not only to determine the place of individual units in comparison to the entrance and each other, but also which routes have the largest volumes inside the building and must be designed easy to travel.*[26]

—St. Olav's University Hospital Enterprise BIM (EBIM)—

The National Building Information Model Standard Project Committee in USA defines BIM as:

> *Building Information Modelling (BIM) is a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition.*[27]

As a building owner with a portfolio of new and old buildings, with life spans of several decades, St. Olav's University Hospital has identified the need of a homogeneous and standardized open platform to efficiently develop its facilities.

In 2012, the Central Norway Regional Health Authority, with St. Olav's University Hospital as project leader, established the project LifeCycle BIM with the objective of establishing a truly life-cycle BIM–based Facility Management platform. The platform should reflect multiple aspect structures and adapt to new technology and different organizational processes. As a solution to these challenges, St. Olav's University Hospital has implemented an EBIM philosophe, based on a model server, where each building, old, new, or future building, is one integral unit in the entire portfolio of buildings, for which the conditions in terms of room classification systems, product classification, processes, and core business are defined by the hospital owner.

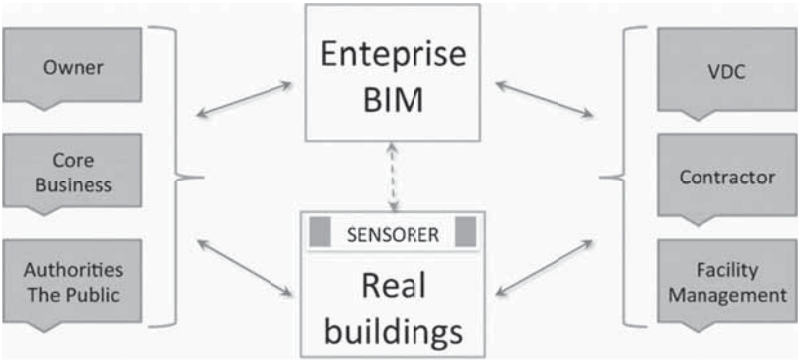


Figure 14.1
St. Olav's University Hospital Enterprise BIM (EBIM) architecture

At St. Olav's University Hospital, EBIM is a discrete information database, targeting important user aspects such as Virtual Design Construction (VDC), Facility Management (FM), and Property Management. In the near future, the EBIM will support important functions in the core business area and be an important source for strategic management and analysis, illustrated in Figure 14.1.

To make EBIM more knowledge-based, sensor technology such as IoT (Internet of Things) and central operations monitoring will play an important role in decision-making, optimizing inventory space, object tracking, labor, and operational costs.

Integrating POE, BPM, and BIM in Hospital Infrastructure

Although the terms evaluation (in case of POE) and models (BPM and BIM) both seem to suggest analysis of a static situation at a certain moment, new technology also enables real time analysis of occupant behavior. Therefore, BIM should not be considered any more as static models but should be regarded more as simulations:

> *Simulation is a dynamic tool that allows testing different scenarios in volume and ways of working* (…) *when the functional changes are ambitious and substantial effects can be hard to estimate through static calculations or other present means of operations*.[28]

A system of building simulation based on occupant data that produces data about the activity behavior of occupants as members of an enterprise structure, can significantly improve the relevance and performance of building simulation tools.

Such a "holistic enterprise modelling and simulation approach should incorporate all levels of business operations."[29] Simulation of the BPM activities within a BIM predicts future occupancy behavior in the architectural layout of a desired organizational concept before it is even built:

> *It can produce the occupants' movements through the building spaces based on execution of the daily business processes' activities and the equipment involved, and as a consequence the occupancy of space*.[30]

This information then can be used to influence the building performance and also feedforward into future building projects. Business Information data can be acquired from many sources creating a data aggregation from which patterns and relationships within an organization can be revealed.

The issue at hand is developing BIM model representations that are able to integrate huge amounts of data and process information. If, in addition, benchmark is to be adopted also, a standardization of the POE approach is necessary for data collection. McGinley describes a scenario in which POE data is combined with analysis technologies that focus on behavioral "pattern of life" to inform the design of buildings.[31] In such a scenario, user behavior patterns from buildings with similar typology could be used in simulations of a proposed architectural layout.

The results of the simulations show the user behavior based on experiences from similar buildings and can be used by the design team to pre-evaluate the proposed design.[32] This requires an approach in which designers take the "ghost" behavior of (lots of) real users of previous examples into consideration. These pre-occupancy simulations could be beneficial to the design and eventually the operation of the hospital infrastructure.

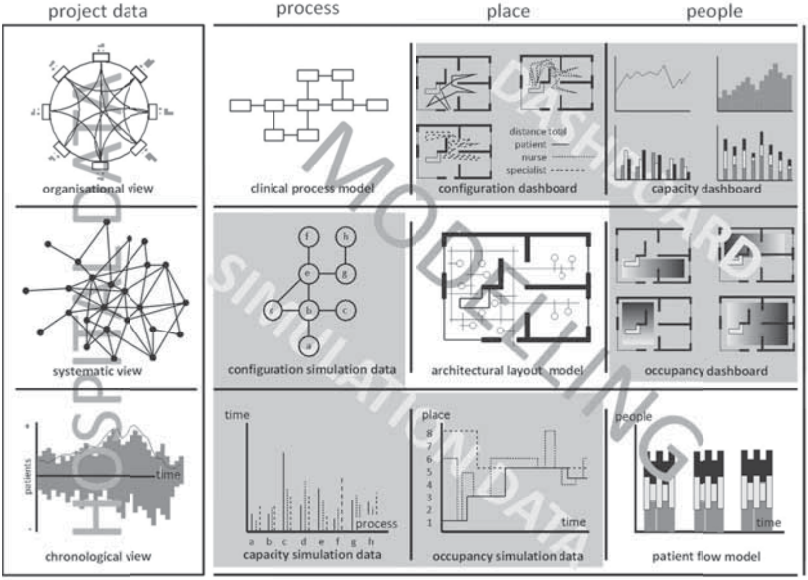
According to McGinley & Fong,[33] the optimum solution is to build these user stories or 'ghosts' based on real behavior from users in a building of similar typology as an aggregated, anonymous swarm of building users. For this purpose, aggregated Business Information data could be anonymized for creating typologies of specific "DesignGhosts."[34]

Blueprint for an Activity-Based Building Simulation Model

Theory and case examples from recent literature on BIM, POE, and BPM show that there is a momentum to integrate separate worlds of modelling for the planning and design of hospital architecture. The integration of Business Process Modelling of clinical processes based on patient logistics in relation to actual places in the hospital infrastructure has the potential to contribute to a more efficient and effective clinical process. But this requires a "fusion of two (currently) separated worlds: BIM and BPM with the occupants as main catalyst."[35] As a first step towards the integration of these techniques, we present in this chapter a blueprint of what could become an Activity-Based Building Simulation Model that connects hospital data, simulation data, modelling, and monitoring of effects in one conceptual framework. For this purpose, a simple example of a small healthcare building consisting of a waiting area, reception, back-office, and two consulting rooms is used as an illustration.

The conceptual framework, presented in Figure 14.2, connects four different elements. Figure 14.2 illustrates the blueprint with a sketch of different models and with a table, which describes the same model cell by cell. The first element of the conceptual framework and point of departure is the hospital data in the left column, which is an analysis and representation of the actual daily processes similar to the techniques used in the Inselspital. The second element in the conceptual framework is the modelling of clinical processes, the architectural layout, and patient flow logistics, visible in the center diagonal of the model. Modelling is a creative element in this framework, in which the hospital data is used to design future processes, layouts, and flows. These models are tested by simulations based on the simulation data, which is located in the left-lower corner of the conceptual framework. Data on patient flows, deviation in number of patients in time, clinical paths, and location of activities from the hospital data is used for generating simulation data: the parameters that are needed for the different simulations.

The forth part of the conceptual framework is the dashboard, which monitors the impact of the alterations in the models on, e.g., travel distances, capacity, needed resources, and occupancy. Within this conceptual framework, the impact of changes in the clinical process model on configuration output and capacity output can be monitored.



hospital data	process	place	people
The organisational structure and how the actual medical activities shape the administrative space: overview of patient flows through the hospital system. **organisational view**	Modelling clinical process based on organisational view: which steps can be combined or eliminated to make the process more efficient? **clinical process model**	Revealing distances and travel time related to the clinical process and the architectural layout: what are the distances for the different users? **configuration dashboard**	Revealing needed capacity or possible demand based on the combination of clinical process, architectural layout and patient flow model. **capacity dashboard**
The operational structure as it emerges from patients flows through the hospital and the way different activities are related. **systematic view**	Generating a spatial configuration for each clinical process based on systematic view for simulating the clinical process model in the architectural layout. **configuration simulation data**	Modelling spatial configuration in an architectural design based on the systematic view: which configuration has an overall reduction of travel distances? **architectural layout model**	Mapping occupants in the architectural layout based on DesignGhost simulation of different typologies and quantities of generated users. **occupancy dashboard**
View on patient flows across time, revealing how quantities change in time. **chronological view**	Generating different user capacity parameters based on chronological view for simulating capacity based on clinical process and patient flow model. **capacity simulation data**	Generating different DesignGhost typologies based on the chronological view: how do different occupants move through the spatial configuration across time? **occupancy simulation data**	Modelling patient logistics and resource capacity: which combination of patient mix and capacity leads to an optimization between demand and capacity? **patient flow model**

Figure 14.2
Blueprint for an Activity-Based Building Simulation Model.

In addition, the consequences for the configuration and occupancy of different architectural layouts can be made visible, as well as the impact of changes in the number of patients, deviations in time, and patient mix. To test, for example, the impact of a change in the clinical process model on the configuration, the configuration simulation data is used for the simulation. To test the impact of patient logistics modelling on the clinical process, the capacity simulation data should be used to make changes visible in the capacity dashboard. Changing one model at the time and monitoring the consequences of that alteration in the dashboard results in an interactive design and building simulation modelling based on activity-based data.

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CHAPTER FIFTEEN

REGULAR REPETITION AND MODULAR PATTERNS IN ARCHITECTURE

ELENA ARNEDO CALVO

Introduction

> *Kublai was a keen chess player; following Marco′s movements, he observed that certain pieces implied or excluded the vicinity of other pieces and were shifted along certain lines. Ignoring the objects′ variety of form, he could grasp the system of arranging one with respect to the others on the majolica floor. He thought, 'If each city is like a game of chess, the day when I have learned the rules, I shall finally possess my empire, even if I shall never succeed in knowing all the cities it contains.'*[1]

This chapter is focused on morphological patterns that make use of regular repetition as a design strategy. A feature that has been present in the history of architecture from the hypostyle buildings and ancient grids of the Mesopotamian, Greek, and Roman cultures, to the present. Our interest is based on regular repetition as a system of composition of the architectural plan, a condition that is often linked to the choice of the construction system and to the flexibility of program and use. As in all design process, randomness and subjectivity are also present. These features allow breaking the rigidity of established rules and distancing the architectural project from bland systematization, thus integrating the architect's knowledge and skill as a key tool in the compositional process.

Approach to a Possible Classification

Regular Repetition System is characterized by being comprised of a series of identical modules, which are associated or combined with each other, following constant internal laws to obtain an extensive pattern provided with rhythm, cadence, and harmony.

In regular patterns, we differentiate those that are the result of the repetition of a single module and we will denominate as *Single Repetition System*; and those in which the pattern is defined as a combination of different elements such that the module's participation in the set is its only *raison d'etre*, and we will denominate as *Complex Repetition System*. From these, wide ranges of possibilities are defined below, as a first approach to their identification:

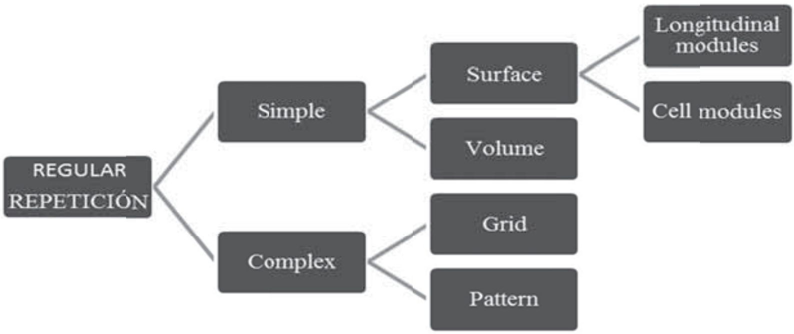

Figure 15.1
Classification diagram.

Simple Repetition System

A *Simple Repetition System* results from the addition of self-supporting module elements, all equal and juxtaposed one over another such that their geometry can cover its surroundings, without leaving gaps, and generate a rhythmic and extensive space. The choice of this module is not easy since the definition of the element itself will imply its potential for growth, the generation of a system, and therefore the configuration of the result. This relationship between the identity of the module and its conception as part of the repetition set requires a continuous path back and forth between the particular and the general scope, in which features such as materiality, geometry, structure, and shape of the module are always present. The resulting configuration is determined by these properties, but also by the type of bond, the number of modules, and boundary conditions. Thus, both internal and external laws of the repetition system will be part of its configuration. This type of repetition system is set out on the surface defined by the X and Y (*Surface Repetition*) axes on the ground plane.

At times, the module follows a three-dimensional logic law to occupy different planes of z-axis (*Volumetric Repetition*) and amplify the degree of interaction between modules that provide greater complexity to the system.

Surface Repetition

Surface Repetition is formed by a single repeat module, which multiplies and adheres to its equals with a constant and uniform rhythm to generate an extensive and generally isotropic space. Its value lies in the module definition as an individual element, which, in its addition element by element, manages to resolve the internal logic of the architectural ensemble. This methodology allows the project to remain open in its limits of aggregation, which confers it a great capacity of interaction and adaptation to its immediate surroundings, whilst achieving its own border definition. In accordance with the geometric and formal characteristics of these repeat elements, the system can grow in one or several directions, which helps us to make a further distinction between the longitudinal and cell repetition systems.

Longitudinal Repetition System: This type of repetition system consists of the addition of longitudinal modules, equal and with a rectangular plan, which adhere to each other under a unidirectional and extensive spatial logic. The module shape is marked by the construction rationality of the roof structure, and its longitudinal walls promote the parallel addition, being the spatial configuration building the result of the interaction between several longitudinal or shed modules. The origins of the longitudinal modules may be found in Arab mosques or in old medieval shipyards. In them, a gabled roof rests on structural planes supported by pillars, generating a continuous and isotropic space despite the shed´s own directionality. This is possible thanks to the addition of equal modules with the same section, free of structural and functional hierarchy, joined by the homogeneity of the roof construction system (usually made of wood beams and boards). This structural serialization system achieves a modern open plan concept that even nowadays is used profusely in architectures such as the Kimbell Art Museum in Texas by Louis Kahn (1972), the National Museum of Roman Art in Merida by Rafael Moneo (1986), or the Sea Museum in Vigo by Aldo Rossi and Cesar Portela (2002).

Cell Repetition System: In this case, the repeat modules are also equal, structurally independent, and joined along a construction rationality that generates a regular structure that is accurate, continuous, and of extensive growth. As in the simple repetition of longitudinal modules, this system has the ability to continue adding units to fill out the surrounding space, without leaving gaps or creating discontinuities. However, unlike the latter, it adds multidirectionality, that is, the multiplication of the module element not only linearly in the X- or Y-axis, but also able to do both X and Y, or XY, since it only relies on its geometry. The origins of the cell repetition systems can be established around the use of the vault and domes as a series roofing system. Their proliferation and development as a project mechanism is linked to the use of wrought iron and concrete structures that, since the mid-nineteenth and early twentieth century, allowed builders to lighten constructions and to generate large continuous and covered spaces. One example of this architectural type is the Reading Room of the *Bibliotheque Nationale*, Paris, by Henri Labrouste (1860-1867). The flexible configuration allows for functional adaptation, without losing the identity of each one of the modules, as is the case in the Johnson Wax Company Building's by Frank Lloyd Wright (1939), the Jewish Community Centre by Louis Kahn (1959), the Palazzo del Lavoro in Turin by Pier Luigi Nervi (1961) and the Orient Train Station in Lisbon by Santiago Calatrava (1998).

Volumetric Repetition

It is characterized by the volumetric occupation of space through the module definition. Its structure and material configuration allow modules to be stacked at different levels whilst, at the same time, interacting with their peers to define a functional space to suit the building´s program. The choice of its geometry will determine the possible relationships between peers and the occupation of space, since not all the polyhedra have the property of filling it.[2] The architect has to know, scientifically or intuitively, the repertoire of different geometries that may suit his or her purposes, trying to "create systems capable of creating other systems,"[3] as otherwise the project would be born dead without any possibility of development. The repetition module is designed as a container of functions, which is multiplied three-dimensionally establishing different types of relationships with peers. The cases that interest us are those who are generated by an ordered addition, such as the Genocide Museum in Sumarice by Ivan Antić and Ivanka Raspopovic (1967), the Nagakin Capsule Tower in Tokyo by Kisho Kurokawa (1972), or the New Museum of Contemporary Art, designed by Kazuyo Sejima and Ryue Nishizawa (SANAA) with Gensler (2007); or those generated by discontinuous jumps, such as Habitat 67 by in Montreal by Moshe Safdie (1967) and the Orange County Government Centre in Goshen by Paul Rudolph (1971). Both types are able to generate a three-dimensional mesh, where we can identify the mass and voids, the rhythm, and cadence of the repetition system, leaving aside the "simple" stack concept.

Complex Repetition System

The *Complex Repetition System* is based on the spatial combination of different elements that completely lose their autonomy and individual identification to become part of a whole. In these repetition mechanisms, the structure, the geometry, and the construction system are designed from the general composition, so that a module can no longer be identified as a repeat unit.

The set features (geometry, rhythm, directionality, etc.) and the multiple interrelations between the different elements (functional connections, circulations, etc.) provide the system with rigidity and dependence, differing in this point from the previously mentioned *Simple Repetition. Complex Repetition* uses elements with complementary geometries and dimensions to define a repetitive combination of spaces based on constant internal laws, whose properties do not depend on the direction of growth (isotropic configuration). Their extensible and unlimited character is highly functional, and it gives spatial flexibility to the program, expanding the possibilities of adaptation and integration with its immediate surroundings. Within complex repetition, we can distinguish between two main groups: grids and patterns.

The *Grids* are extensive systems that are composed of a constant combination of one or more geometries. Their formal configuration as a homogeneous network has implicit a certain freedom or functional randomness that frees them from any form of hierarchy, and whose constructive characteristics are inherent to its formal, structural, and spatial bond. This interdependence, as a configurative system, follows the unlimited and open extension criteria characteristic of the repetition mechanisms, but prevents the subdivision or isolation of its parts. Its origin could be in the layouts of Greek and Roman cities, as geometric grids and structural organization, although they are free of any functional hierarchy. Projects that share these characteristics are the Orphanage of Aldo van Eyck in Amsterdam (1960), the Yale Center for British Art in New Havenel by Louis Kahn (1974), and the MUSAC, Castilla and León

Contemporary Art Museum by Luis Moreno Mansilla and Emilio Tuñón (2005).

The *Patterns* are configured by repeating functional units that already have an organized internal layout, and they bind to similar units through complex projective relations. The repeating pattern is based on the response to use and spatial needs, through the articulation of functions and its connections.

The flexibility and consistency of the composition is such that although specific elements can appear to alter serialization, the system maintains its logic and continuity without suffering substantial morphological variations. Its origin could be established in the Arab Kasbah, oriental palaces, and development of medieval abbeys and monasteries; and in the palaces of the Roman Renaissance and hospitals SXV-XVI, in which the units are formed around courtyards where circulations and functional hierarchies marked pattern linkages. This compositional system is found in Le Corbusier's proposal Hospital Venice (1965), the Centraal Beheer Insurance Co. Building by Herman Hertberger Apeldoorn (1972), and The Freie Universität Berlin by Georges Candilis, Alexis Josic, and Shadrach Woods (1973).

Discussion

The *Regular Repetition Systems* are “open” systems that are used by the architect in circumstances where the restrictive conditions of the project are seen as opportunities for project development (uncertainty or irregularity of the plot, steep topography, etc.). In the words of Allen: “When working with and not against the place something new occurs to record the complexity of what is given.”[4]

The architect’s intuition implements the theoretical process of geometric abstraction and the search for relationships between parts of a whole. An experimentation that uses the structuralist thought, “form matter, but not the shape of things as being ways things,”[5] to obtain an architecture that accepts evolution and change as part of the building’s life.

The respect of its architectural identity makes it possible that, in their ability to remain “open,” these systems may undergo transformations and even assimilate functional changes over time (as it happened in the mosque-cathedral of Cordoba), without altering their morphological pattern. The mechanisms of regular repetition generate buildings with great spatial homogeneity, which needs to be defined with other project tools such as working the section or defining their limit to obtain a strong architectural concept. In Corrales's words: "Works are structure systems. But if you follow them from the beginning to the end, you end up bored and it is very tedious. The important thing is to know how to break it, that's the difficulty."[6]

Notes

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CHAPTER SIXTEEN

SEMANTIC STRUCTURE OF FORMAL DOMAINS AND METHODS FOR THE DEVELOPMENT OF GENERIC GRAMMARS

JOSÉ NUNO BEIRÃO

Introduction

The term "generic grammar" has been frequently used in recent years. Its use refers to the development of grammar formalisms dedicated to large areas of design—that we shall call "Design Domains"—with the aim of implementing design support tools in these areas. One of the main interests of the approach is the fact that such implementations try to move away from the "tyranny" of the traditional analytical examples usually focused on reusing classical design languages by moving to areas of generative design such as tableware design, chair design, and urban design.[1] Examples of the classical approach are countless—Palladian Villas and Frank Lloyd Wright's Prairie Houses being the most common examples[2]—but, albeit such intense and already long use of shape grammars in analytical studies, its use to support design generation is reasonably limited, even disappointing. The classical examples have been perhaps responsible for a rather limited use of shape grammars in design exploration even though shape grammars are claimed by followers to be quite powerful in terms of supporting emergent formal spaces for design exploration. The "generic grammar" approaches to the use of shape grammars try to develop very broad sets of design rules that can have a very generic application in a design domain and hence be regarded as language independent; that is, able to generate formal diversity for free design exploration. The proposed work of the designers becomes, in this approach, the task of finding the specific set of rules to apply including defining the specific level of detail, the specific set of parameters, and the specific allowed variability.

In other words, the designer searches and finds a specific subset of the generic grammar that defines his or her response to the design problem including its specific language or formal style.

Precedents: Production Systems, Patterns, and Shape Grammars

In Gips & Stiny,[3] the authors propose a uniform characterization for Post production systems[4] defining them as composed of the following: (1) the objects they process, (2) their definitions, (3) their interpretative mechanism, and (4) the objects they generate. This uniform characterization shows us most algorithmic structures as production systems defined by the form $u \rightarrow v$ where u and v are objects from a uniform class, C, of well-defined objects, where objects may be seen as shapes or symbols or combinations of both like labelled shapes,[5] and the move, →, is an acceptable transformation in the object domain. The concept of patterns, as developed by Alexander *et al*.,[6] sees a recurrent state of affairs in our environment, which may be described as a problematic predicate condition for which repeated evidence along time has provided time tested solutions; a transformation of the state of affairs that provides a consequent design solution. Rules assume the form *predicate → consequent.* Therefore, u corresponds to some predicate state condition for which a well-known design transformation produces a consequent solution v. The interesting aspect of the pattern language theory is that Alexander *et al*. provide a verbal description of the matching conditions (*predicate*) upon which a designer may apply a simple set of instructions described verbally with some additional diagrams to produce a traditional solution (the *consequent*); the algorithmic structure is both precise and open to interpretation. However, following this theory, Gamma *et al.*[7] proved that the same principles could be applied in computer programming by providing a sample code instead of the verbal instructions. In fact, if we think of the pattern language concept for computer implementation we would easily see that the algorithmic description should clearly be provided by some form of production system or compound form of production systems probably involving shape grammars. Shape grammars, as stated by Gips & Stiny,[8] are production systems where u and v are labelled shapes and $u \rightarrow v$ applies a transformation, $t(u)$, to any Euclidean variation of u (symmetry, rotation, or scale), such that—

$$d_1 = (d - t(u)) + t(v)$$

In other words, the design d_1 is the result of subtracting a Euclidean variation of the shape *u* from a design d and adding the transformation of the shape *v*. In a parametric environment, the shape *u* corresponds in fact to any assignment of values *g(u)* to the parameters of shape *u*. Therefore, the equation 0 becomes—

$$d_1 = (d\text{-}t(g(u))) + t(g(v)))$$

The Urban Design Domain and its Description

In the urban design, domain designers operate with shapes (*S*) and symbols (*L*) representing urban concepts. The specifications of the conceptualization are defined by an ontology[9] that describes the urban design domain starting from its primitive representations and following by detailing all its component parts. An ontology describes a design domain in terms of the objects (or individuals) composing it, how they cluster in a structured classification identifying the classes and subclasses of objects that form the domain (taxonomy), their attributes (both object and class attributes), and the expressed relationships between them (topology).

Objects are singularly identifiable entities represented by a geometric component (a shape *S*) and a label (*L*). Among these labelled shapes, one may find objects with an empty label part or with an empty shape part. Objects with an empty shape part are simple classifiers of concepts, symbols, or even technical terms that may be used as classification vocabulary. Objects with an empty shape part are mere geometries without semantic value other than their geometric properties.

Classes define the taxonomy of objects by classifying them according to their unique characteristics. The taxonomic structure also defines a dependency structure by identifying which objects are composed of other objects, or, in other words, by identifying the subclasses of other classes. Objects that are not composed of other objects shall be called primitives (e.g., points and labels). The specifications of a class are defined by the attributes of their objects or generic attributes of the class. The dependency structure is settled by the expressed relationships declared between classes. Classes are composed of shapes, labels, or labelled shapes depending on the concept they represent and have the form—

$$C_i = \{S_i, L_i\}$$

—where i is an index class identifier (according to the cells number in Figure 16.1).

A simplified representation of the urban design domain can be seen in Figure 16.1.

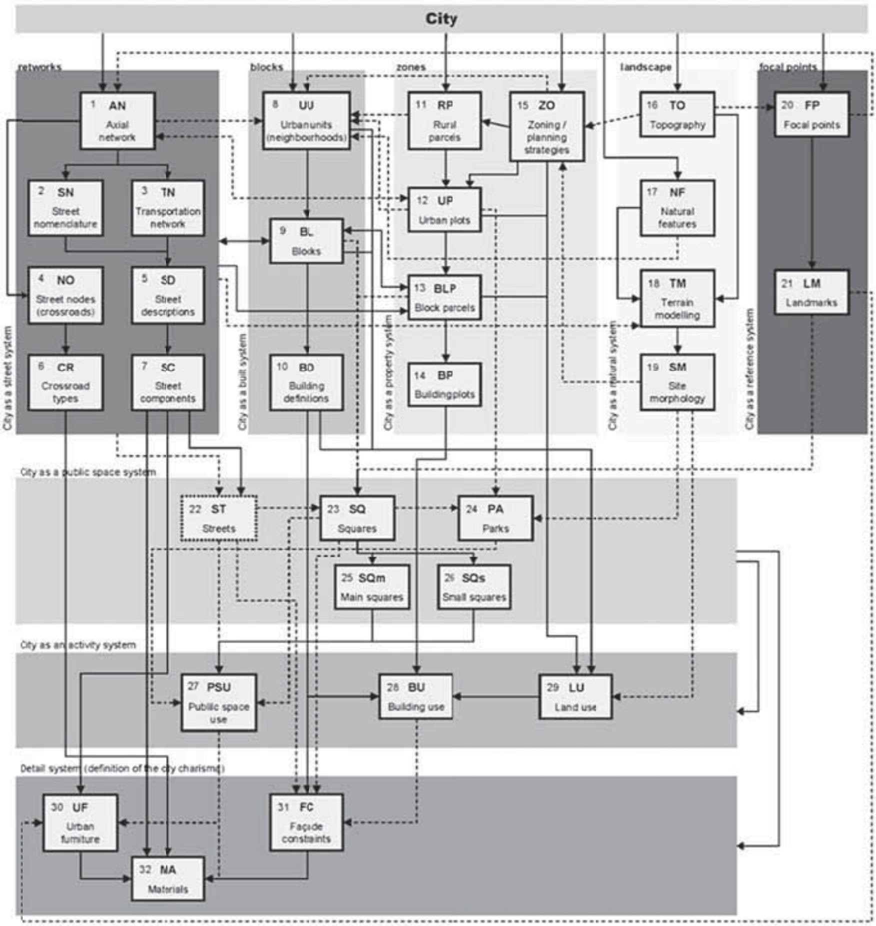

Figure 16.1
The ontology of the urban design domain.

The overall ontology is subdivided in several sub-ontologies that classify different representational paradigms of the urban design domain that we shall call systems. For instance, (1) the city seen as a street (or network) system, (2) the city seen as a built system, (3) the city seen as a property system. Each system can be seen individually or as part of the overall context and as such may be isolated for analytical purposes. For instance, system (1) can be subject to several known methods of network analysis; system (2) may be used for morphology analysis, or even combined whenever such combination pursues a specific purpose. Each system can be further detailed by specifying its sub-classes. For instance, in system (1) we may find several levels of descriptions of the street network. The top class represents the street centerlines providing a representation of the street network in the form of an axial representation (AN). These representations can be further classified by adding features from pure classifier classes such as Transportation Network (TN) and Street Nomenclature (SN). The former associates a street with its role in the network as part of a transportation system—streets can be classified as "distribution streets," "local distributors," "local access streets," etc. The latter class adds a name provided by the local natural language, for instance, avenue, boulevard, cul-de-sac, grove, alley, etc. Street Descriptions (SD) describe streets defining their minimum component requirements depending on the previous set of classifications. Street Components (SC) are defined in terms of the functional corridors considered while defining the typical street section—the functional corridors can be car lanes, bicycle paths, sidewalks, parking lanes, bus lanes, etc. For further detail see CItyMaker (tables 2-5).[10] Other systems may be described following identical reasoning and in principle, according to ontology theory, can be extended and updated anytime.[11]

Urban Design Patterns

Shape grammars operating on objects found in the ontology shown in Figure 16.1 are constrained by the semantic structure embedded in it, producing therefore consistent designs where representations are composed of shapes and symbols representing parts of the urban environment and other descriptions that semantically complete them.[12] Typically, shape grammars operating within a single class of the ontology are algebras of the format $\gamma_i = \{S_i, L_i, R, I_i\}$ where S_i and L_i are shapes and symbols in an object class C_i, I_i is an initial labeled shape in the same class, and rules R apply productions of the form $u \rightarrow v$ on objects u and v from class C_i.

All designs produced by such patterns are kept within the same algebra ($\gamma_i \rightarrow \gamma_i$). These are the most common urban design patterns in an Urban Grammar Γ' (Figure 16.1). Patterns initiating the design generation process are called initial patterns. In urban design, initial patterns start always from some initial shape, meaning a pre-existing object *E* in the existing urban context that may be accepted as a "trigger" for some kind of urban design move. Rules of these kind transform *E* into some object *u* where *u* is a labelled shape belonging to a class C_i—

$$E \rightarrow u, u \in C_i = \{S_i, L_i\}$$

These rules allow the initialization of the generation of designs with a particular object class C_i ($E \rightarrow \gamma_i$), meaning that they initialize the appearance of a specific type of urban objects in the design. It also means that the patterns of the type previously referred, those operating within the same pattern, can now be applied.

Likewise, some patterns can transform objects from one class into objects of another class. For instance, urban blocks (BL) can be subdivided into buildings (BD). Regarding these patterns, there are two kinds that should be considered. The difference lies in the rules transforming objects from upper (level of abstraction) ontology into a lower (level of abstraction) ontology ($\gamma_i \rightarrow \gamma_j$) or vice-versa ($\gamma_j \rightarrow \gamma_i$). The former defines the semantic relation *u* has *v* while the latter defines the relation *v* is part of *u*. In the former, rules assume the following format—

$$u \rightarrow v, u \in C_i \wedge v \in C_j$$

—where the semantic relation is *u* has *v* and the algebra γ_i opens the application of a new algebra γ_j allowing the design to be further detailed. Conversely, the relation *v* is part of *u* produces rules of type—

$$u \rightarrow v, u \in C_j \wedge v \in C_i$$

—where an algebra γ_j allows further development of upper level abstraction parts of the design by generating new objects from an already opened algebra γ_i. These rules allow fine-tuning of the design, producing what, in design thinking, could be called corrective feedback loops. The several levels in the ontology not only help to keep the semantic structure clear, but also provide a clear means for separating design phases.

The main idea behind the pattern language concept is to define an algorithmic approach to architectural and urban design by providing a set of common design instructions already shown to be efficient in solving specific design problems. In Alexander *et al*., patterns provide verbal descriptions on the conditions upon which to apply a solution that is also verbally prescribed.[13]

The idea presented in this chapter follows the work presented in CItyMaker,[14] where patterns describe typical urban design operations both verbally and algorithmically in the form of a discursive grammar by specifying the rules (*R*) that generate such design operations.[15] Patterns also specify the objects they operate on, the classes they belong to, the class of objects they can generate, and sometimes some attribute constraints providing semantic guidance to rule application.

The whole set of urban design patterns forms a generic grammar for urban design that can be applied in many different contexts. In more detail, the complete set of patterns defines a generic grammar for urban design—the Urban Patterns Grammar Γ. Considering a hypothetical system where additional design patterns γ' that may be customized by the grammar user, the union of all grammars in the Urban Patterns Grammar Γ with all customizable grammars γ' defining a theoretically infinite set of grammars that should be able to generate any kind of urban design—the Universal Urban Patterns Grammar Γ∞ (see Figure 16.2).

The Urban Design Patterns (called Urban Induction Patterns in CItyMaker) replicate,[16] with some amount of flexibility given to the designer, a typical urban design operation given by a discursive grammar of the format—

$$\gamma_i \rightarrow \{D, U, G, H, S_i, L_i, W, R, F, I_i\}$$

This complex format was considered to address the complexity that semantic contextualization brings to urban design problems. Sets *D* and *G* address both descriptions of designs and descriptions of goals. Goals G are the result of an urban program formulation procedure using tools and methods.[17]

The urban program formulation will not be addressed in this paper. Goals are described in the form of description rules for which descriptions of designs that meet the goals are given by description rules in the set *D*.[18] These descriptions guide the application of rules *R* operating on shapes and symbols S_i, L_i from an object class C_i.

A set of heuristics *H* constrain the rule applications within design spaces constrained by best practices. A set of functions *F* applies regulation constraints and may be modified or adapted according to different contexts. Weights *W* open another set of functions that allow design interactivity by opening space to users to choose between options they consider more important than others, hence guiding the generation of designs according to expressed preferences given by the designer.

Designing with Patterns

As in regular design procedures, designers develop their projects systematically, applying design operations corresponding to exploratory moves towards a design solution. Such moves are abstractly programmed in the form of Urban Design Patterns as described above. A full urban design is therefore obtained by applying a sequence (in fact, a personal arrangement) of patterns. This particular arrangement of patterns defines a set of design solutions constrained within the specific combinatorial design space set by the grammar composed of the many patterns,—an Urban Grammar Γ' (see Figure 16.2)—their specific sequence and constraints, which we can claim that frames the language of the plan.

The plan is in fact a framed solution space given by the Urban Grammar Γ'. The Urban Grammar Γ' is the Cartesian product of the specific arrangement of Urban Patterns γ_i as shown in Figure 16.2. The Urban Patterns Grammar Γ represents the set of all possible Urban Grammars Γ', or, in other words, the set of all possible designs that are possible to generate, that is, the set of all possible arrangements of Urban Patterns γ_i provided by the design system.

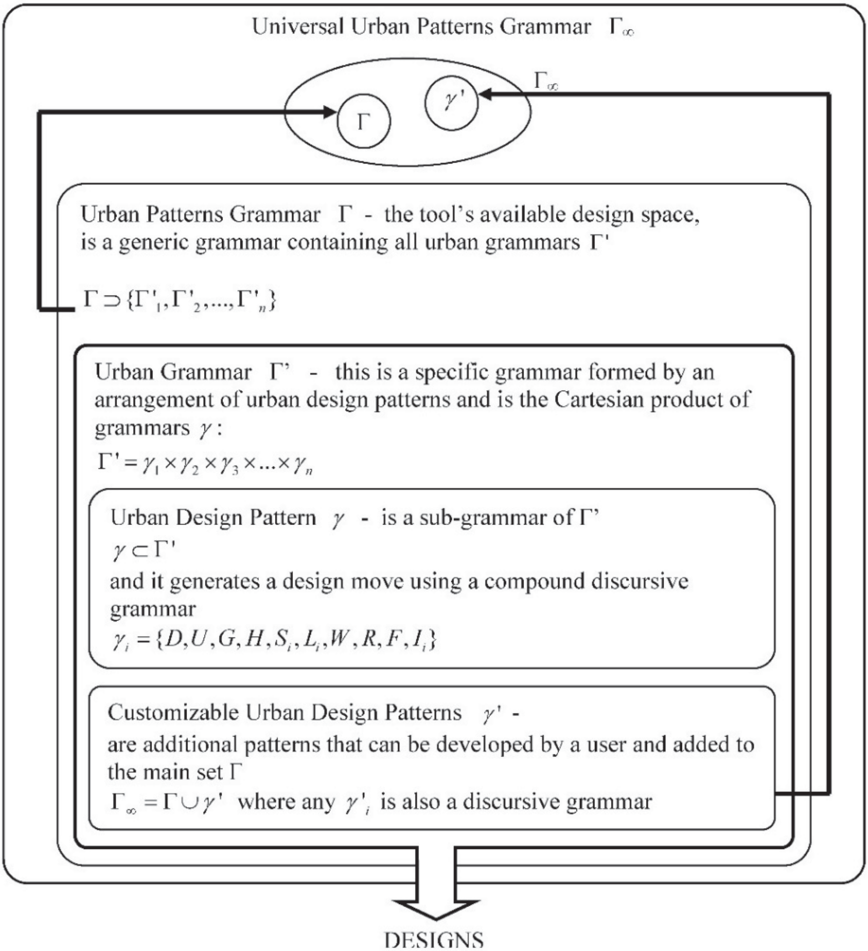

Figure 16.2
The Universal Urban Patterns Grammar and all its sub-grammars.

Any designer willing to program his or her own design patterns, either from scratch or from pattern templates (or customizable patterns γ') may contribute to extend the Urban Patterns Grammar to a theoretical Universal Urban Patterns Grammar Γ∞ able to produce any design desired or needed.

Why Patterns

If any design can be produced with this system, one may ask: why patterns? Why the use of such a complicated set of computational formalisms just to be able to design anything? How can we distinguish good designs from bad ones? These questions have a set of very pertinent reasons:

First, the semantic structure given by the ontology provides a system that generates designs with an ordered and meaningful representation where geometry and symbols (symbols here may even represent meanings, and if not at least properties and attributes are linked to representations) carry the necessary information to support decision.

Second, designing is not a linear process and therefore the designing interface needs to provide space for exploring solutions outside what could be called the space of acceptable solutions. It is the confrontation between properties of unacceptable solutions and acceptable solutions that allows the acceptable ones to be chosen.

Third, if a design tool is expected to be used in several contexts, its generative features should not be constrained by design preconceptions but only after experiencing several design spaces and confronting results with analysis.

Fourth, analysis is part of the design process. The fact that all designs are consistent with a semantic structure allows development of analysis patterns that can produce several types of design support information. Designers have then, not just a large set of possible solutions to choose from but also an equivalent set of analysis that may support the validation, or not, of those solutions.

Finally, such production of design plus analysis defines design "products" that are transparent and can be objectively discussed with all involved stakeholders. This is a particularly important issue in the field of urban design.

The conclusion inherent in the previous justifications is that such a system is only interesting if seconded by the use of analysis patterns, that is, patterns that are based on the same semantic structure analyze relations between attributes and properties of the generated designs to produce indicators and evaluations on the designs produced by the design patterns. The development of design analysis' patterns is not addressed further in this paper but may be clarified by consulting work on this line of research.[19]

The Need for Parametric Implementations

Parametric implementations of design patterns have two important features for design decisions in complex fields with many decision makers: (1) they provide an insightful flexibility of the design model that allows interactive visual variation; and (2) they provide information on the relation between the formal properties and the performativity indicators in a transparent way. A sensible use of these features enables a team of decision makers to define with reasonable accuracy the allowed variability given to regulatory specifications as well as supporting why such regulatory specifications are given. Results can also be expected to address more efficiently needs defined in terms of adaptability and flexibility of the solution. In fact, flexibility and adaptability are only constrained in practical applications not by the potential of tools to embed flexibility or complex distribution of performance goals but rather by law epistemological discussions on the inequality of rights.

Method for Developing Generic Grammars

A generic grammar is worth developing whenever there is a field of design activity that requires the production of variable sets of solutions rather than a single solution. Having identified such a design domain, one may follow a set of procedures to produce the generic grammar.

1. Define the semantic structure of the design domain by clearly stating the specifications of the ontology describing the design domain: objects in the design domain, their taxonomic structure, their attributes, and the relationships they contain (or their topological structure).

2. Investigate the typical design operations performed by specialist designers in the field, decomposing them into the minimum possible individual design actions and describing them algorithmically.

3. Define all grammars—all kinds of production systems—that according to a semantically correct structure allow the production of designs and contents (even semantic contents) that describe valid solution spaces for the abstract design moves.

4. Combine grammars to test their interoperability. Convert grammars into combinatorial parametric patterns and test the generation of interactive models.

5. Define what properties, attributes, indicators, and evaluation procedures can provide information support for design decisions and develop algorithms (patterns) to calculate those analyses. Additionally, integrate analysis visualization tools working in real time with the generation of solutions so that you can store both the solutions and the results of the analysis.

The concepts and method given in this paper are exemplified with the complex case of the urban design domain and presuppose the complexity introduced by the need to develop interoperability between geographic information systems and parametric design environments (details of the latter can be seen in),[20] but they are in principle applicable in any areas involving a simpler description. This paper also provides a rigorous notation for such task.

Acknowledgements

The author would like to thank José P. Duarte for his readings and comments, and especially his contributions regarding the development of the "generic grammar" concept that emerged during the development of the City Induction research—http://cityinduction.fa.utl.pt/.

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CHAPTER SEVENTEEN

A COMPOSITIONAL SCHEMA FOR THE AUTOMATED GENERATION OF BEST CONNECTED RECTANGULAR FLOOR PLANS

KRISHNENDRA SHEKHAWT
AND JOSÉ P. DUARTE

Introduction

An important task in the initial stages of the architectural design process is the designing of planar floor plans that are composed of non-overlapping rooms divided from each other by walls, to suit given topological and dimensional constraints. A *floor plan* is a polygon, the plan boundary, divided by straight lines into component polygons called *rooms*. The edges forming the perimeter of each room are termed *walls*. The region not enclosed by the boundary is called *the exterior*.

The *topological constraints* are usually given in terms of adjacencies between rooms and with the exterior of the plan. Two rooms in the floor plan are *adjacent* if they share a wall or a section of wall. Interconnections between rooms and with the exterior, and natural lighting or ventilation into the rooms, are often reasons for such constraints. The *dimensional constraints* involve shapes or sizes of each room and the actual floor plan. For detailed discussion regarding definitions related to floor plans, refer to Rinsma.[1]

A *rectangular floor plan* is a floor plan in which the plan boundary and each room are rectangles. A rectangular floor plan can be generated in the following ways:

i. *Addition:* it concerns the addition of rectangular pieces, like tiles, to produce a rectangular plan (see Krishnamurti & Roe);[2]

ii. *Dissection:* it concerns the division of a large rectangle into smaller rectangular pieces. This process is called *rectangular dissection* (see Mitchell *et al*., Earl, Flemming, Bloch & Krishnamurti, Bloch).[3]

In this work, the rectangular floor plans are generated by addition of rooms. Here, dimensional constraints involve the size of each room while the topological constraints are given in terms of the *connectivity of the floor plan*, which is derived from adjacency relations among the rooms and is important for any architectural design; if two rooms are adjacent then it is possible for them to be made accessible to each other via a door. In addition, the overall patterns of adjacency determine the circulation routes in a building. Furthermore, rooms having adjacencies to the exterior can have windows thus enabling natural lighting and ventilation.[4] In the past, Grason graphs and rectangular dualization techniques were developed to address the requirement for adjacency.[5] In addition, Roth considered adjacency between the rooms for constructing a rectangular floor plan.[6] Recently, Wong and Chan proposed evolutionary algorithm for finding best adjacencies between functional spaces and showed that it can be a very useful tool for architectural layout design tasks.[7] In this chapter, we look for only those rectangular floor plans that are best connected.

The *connectivity of a floor plan* is given in terms of the connectivity of the corresponding adjacency graph. The *adjacency graph of a floor plan* is a simple undirected graph obtained by representing each room as a *vertex* and then drawing an *edge* between any two vertices if the corresponding rooms are *adjacent*. This type of adjacency graph is called the *weak dual* given by Earl & March.[8] In this definition and in this work, exterior has not been taken into account, but we aim to consider it in future.

The *degree of connectivity* of a floor plan is derived by computing the number of edges in the corresponding adjacency graph. If two floor plans are made up of the same rooms, then the floor plan whose adjacency graph has more edges is considered to be *more connected.*

From Shekhawat,[9] we know that the adjacency graph of any rectangular floor plan with n rooms has at most $3n - 7$ edges, provided that $n > 3$ (for proof, refer to Shekhawat, Theorem 2).[10] It implies that a rectangular floor plan is *best connected* if its adjacency graph has $3n - 7$ edges.

From here on we represent rectangular floor plans by R^F and best connected rectangular floor plans by R^F_{BC}. Also, $R^F(n)$ stands for a R^F made up of *n* rooms.

In most of the work, we found that the topological constraints are given in terms of the adjacency requirement graph, which is generally a spanning sub-graph of the adjacency graph of the final plan. It means that, if the adjacency requirement graph has *a* edges and the final adjacency graph has *b* edges then $a \leq b$. However, the adjacency graph of final R^F can have at most $m = 3n - 7$ edges (*n* is the number of rooms and $n > 3$). Therefore, we are looking for those R^F only that are best connected, i.e. their adjacency graph must have $m = 3n - 7$ edges. Our strategy is to obtain a R^F_{BC} while satisfying the dimensional constraints.

In 2013, Shekhawat presented an algorithm called *spiral-based algorithm* for the construction of a best connected R^F.[11] The obtained R^F are termed *spiral-based rectangular floor plans*, denoted by R^F_S. Nevertheless, there may exist other R^F_{BC} which are not congruent or similar to the R^F_S. In this work, we are looking for the R^F_{BC} that are not congruent to the R^F_S, i.e. having different compositional schema than that of R^F_S. For the definition of congruent rectangular floor plans, refer to Section "Best connected non-congruent rectangular floor plans."

It may not be difficult to find a $R^F(n)$ having $3n - 7$ edges in its adjacency graph but the automated generation of a R^F_{BC} is difficult and different from finding a R^F_{BC}, as explained below. An *automated best connected rectangular floor plan* is a R^F, which is rectangular and best connected for any number of rooms. Here, *automated generation of a* R^F_{BC} is about providing an algorithm that gives a R^F_{BC} for all values of *n*.

For example, consider Figure 17.1, which is best connected for four rooms, and it may be best connected when $n < 4$ but, in any case, it would not be rectangular for three rooms (consider deleting one to decrease n from 4 to 3) and it cannot be extended to remain best connected for five rooms because to remain best connected the 5^{th} room should be adjacent to three existing rooms, which is not possible for Figure 17.1 (consider adding a room so that the plans remains rectangular). It means that Figure 17.1 is a R_{BC}^{F} but it is not an automated R_{BC}^{F}, meaning that it was not generated by an algorithm that can generate R_{BC}^{F} for any n. The architectural implications of this are that if an architect is generating a floor plan to satisfy given adjacency requirements and s/he is not following an algorithm that can generate best connected floor plans for any n, they might find themselves in a dead-end situation, having to backtrack. This problem is particularly acute in the design of buildings with a large number of rooms and significant adjacency requirements.

If it is required to construct a rectangular floor plan for the given rooms of different sizes, without changing the width and length of any room and without any overlapping, then there could be some extra spaces inside the obtained floor plan.

As such, in this chapter, we propose an algorithm called *C-RLAB* (the explanation of the name is connected to the way rooms are allocated, which is given below after the algorithm is described), to generate an automated R_{BC}^{F} (other than R_{S}^{F}) with extra spaces. Future work will explore other best connected compositional schemes.

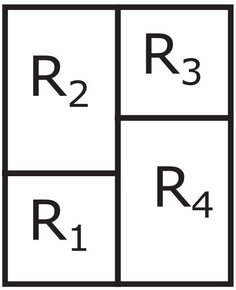

Figure 17.1
A best connected rectangular floor plan for 4 rooms.

Best Connected Rectangular Floor Plans

In this Section, first, we present an algorithm to construct a rectangular floor plan and then we will show that it is best connected. Suppose we have given n rooms, dimensions (width and length) of each room and the problem is to automatically fit all the rooms inside a rectangle, without changing the width and length of each room, in such a way that the obtained rectangular composition should be best connected.

Let R_i denote the i^{th} room. Let D_i^h and D_i^v be the *width* (dimension of the room R_i measured horizontally) and *length* (dimension of the room R_i measured vertically) respectively. Please keep in mind that length in this case does not refer to the largest dimension of a rectangular room but just to the vertical one.

Let the rectangular composition obtained after allocating *i* rooms be denoted by $R_{BC}^F(i)$. D_i^H and D_i^V are the width and length of $R_{BC}^F(i)$, which are computed as follows:

For *i*=4*n*+1 or *i*=4*n*+2 we have $D_i^H = \max\left(D_{i-1}^H, D_i^h\right), D_i^V = D_{i-1}^V + D_i^v$ where *n* = 0, 1, 2...

For *i*=4*n*+3 or *i*=4*n*+4 we have $D_i^H = D_{i-1}^H + D_i^h, D_i^V = \max\left(D_{i-1}^V, D_i^v\right)$ where *n* = 0, 1, 2...

For the above sequence, we assume that $D_0^H = 0$ and $D_0^V = 0$.

From here on, R_{BC}^F stands for an automated R_{BC}^F. Here, we present an algorithm which automatically generates an R_{BC}^F with extra spaces.

In the discussion that follows, *n* is the total number of rooms to be allocated and *i* is the index of the room that is being considered for allocation.

C-RLAB Algorithm

For the better understanding of the algorithm, its steps are associated with an example, say Example 1, where we have been given six rooms with their width and length as follows:

$R_1 : (1 \times 1), R_2 : (2 \times 1), R_3 : (2 \times 3), R_4 : (3 \times 2), R_5 : (5 \times 4), R_6 : (6 \times 5)$

Through this example, we will discuss the construction of $R^F_{BC}(6)$ as illustrated in Figure 17.2K. The order in which the rooms are arranged to obtain a rectangular floor plan using the C-RLAB algorithm is called the *order of allocation*. Clearly, for the *n* rooms, by considering each order of allocation *n*! rectangular floor plans can be obtained. To choose the order of allocation to be used and to minimize the size of extra spaces, we follow the steps given below:

i. Compute the area of all *n*! R^F,

ii. Pick the one having least area and extract the order of allocation of the corresponding R^F,

iii. Apply the C-RLAB algorithm by considering the order of allocation derived above.

Here are the steps of the algorithm:

i. For understanding the steps of the algorithm, we consider the following order of allocation: $R_1, R_2, R_3, R_4, R_5, R_6$ (at the end of this section, we present the minimum area R^F among $n!$ R^F for the input of Example 1).

ii. For *i* = 1, allocate R_1 at a position, say (*x*, *y*) (see Figure 17.2A).

iii. Increase *i* by one and allocate next room, say R_i, below the last obtained rectangular composition $R^F(i-1)$ in such a way that its upper left vertex is the lower left vertex of $R^F(i-1)$. For example, in Figure 17.2B R_2 is allocated below R_1.

In this step and in all the upcoming steps, after drawing R_i, we draw an extra space, if required, to get a rectangular composition with width D_i^H and length D_i^V.

For this step, if $D_i^h > D_{i-1}^H$, an extra space is drawn to the right of $R^F(i-1)$. On the other hand, if $D_i^h < D_{i-1}^H$, an extra space is drawn to the right of R_i. For example, in Figure 17.2C, an extra space is drawn to the right of R_1.

It should be clear from this step that, in this algorithm, after positioning each room, our aim is to obtain a rectangular composition of all the positioned rooms; and to achieve the rectangular composition, sometimes an extra space is required. This idea of the extra spaces guarantees that, in the end, we will have an automatically generated R^F irrespective of the size of rooms.

iv. Increase *i* by one and draw R_i to the right of $R^F(i-1)$ such that its upper left vertex is the upper right vertex of $R^F(i-1)$. Compare D_i^v and D_{i-1}^V and then draw an extra space if required.

For example, in Figure 17.2D, R_3 is allocated to the right of $R^F(2)$ and in Figure 17.2E, an extra space is drawn below $R^F(2)$.

v. Increase *i* by one and draw R_i to the left of $R^F(i-1)$ such that its upper right vertex is the upper left vertex of $R^F(i-1)$. Compare D_i^h and D_{i-1}^H and draw an extra space if required.

For example, in Figure 17.2F, R_4 is allocated to the left of $R^F(3)$ and in Figure 17.2G, an extra space is drawn below R_4.

vi. Increase *i* by one and draw R_i above $R^F(i-1)$ in such a way that its lower left vertex is the upper left vertex of $R^F(i-1)$. Compare D_i^v and D_{i-1}^V and draw an extra space if required.

For example, in Figure 17.2H, R_5 is allocated above $R^F(4)$ and in Figure 17.2I, an extra space is drawn to the right of R_5.

vii. Keep repeating Steps 3 to 6 until all the rooms are allocated. For example, R_6 is drawn below $R^F(5)$ to obtain $R^F(6)$ as illustrated in Figure 17.2J and an extra space is drawn to the right of R_6 to get the desired result (see Figure 17.2K).

Figure 17.2
Construction of a best connected rectangular floor plan for six rooms.

In the algorithm (previous page), first two rooms are arranged in the center and then the next rooms are arranged in the order right, left, above, and below, therefore we call it the *C-RLAB algorithm* and the obtained R^F are denoted by R_{BC}^F. The $R_{BC}^F(6)$ in Figure 17.2K has area 84. As discussed above, 6! = 720. $R_{BC}^F(6)$ can be obtained for the given rooms by changing the order of allocation. By computing the area of all 720 $R_{BC}^F(6)$, we found that the minimum area $R_{BC}^F(6)$ has order of allocation $R_4, R_2, R_3, R_1, R_5, R_6$ and area 72 (see Figure 17.3).

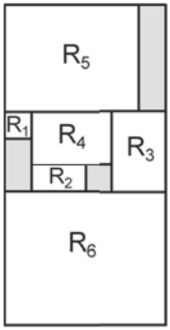

Figure 17.3
Minimum area best connected rectangular floor plan for six rooms.

By applying the definition of adjacency between rooms given in Shekhawat (Section 4),[12] we can easily obtain the adjacency graph of the $R^F(6)$ shown in Figure 17.2K (see Figure 17.4) in which the number of edges are $3n - 7 = 3 \times 6 - 7 = 11$. It implies that the $R^F(6)$ is best connected. In addition, we can easily verify that, if the next room is drawn according to the R-CLAB algorithm, it would always be adjacent to exactly 3 existing rooms, i.e. if $R_{BC}^F(k)$ has $3k - 7$ edges then $R_{BC}^F(k+1)$ has $3k - 7 + 3 = 3(k + 1) - 7$ edges. Hence, the number of edges would always be $3n - 7$ for n rooms when $n > 3$. By considering mathematical induction on n, we can say that *all the rectangular floor plans generated by the R-CLAB algorithm are best* *connected*. This concludes that the *R-CLAB algorithm automatically generates a best connected rectangular floor plan for n rooms*.

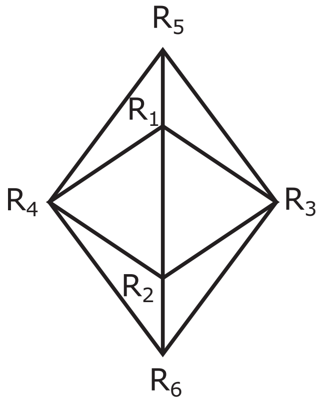

Figure 17.4
Adjacency graph of the rectangular floor plan in Figure 17.2K.

Best Connected Non-Congruent Rectangular Floor Plans

Two rectangular floor plans are congruent if they satisfy the following conditions:

i. They are made up of same number of rooms (size of rooms can be different).

ii. They have the same unlabeled adjacency graphs (an adjacency graph in which individual nodes have no distinct identifications except through their interconnectivity; graphs in which labels are assigned to nodes are called labeled graphs).

iii. One can be transformed into other by some combination of reflection, rotation, and scaling.

iv. One can be obtained from the other by:

   a) Changing the size of rooms,

   b) Interchanging the position of the rooms,

   c) Interchanging the width and length of the rooms.

For example, in Figure 17.5, all sub-figures are made up of 4 rooms R_1, R_2, R_3, R_4 with area 4, 4, 8, 8 respectively. Figures 17.5A, 17.5B and 17.5C are congruent to each other but Figure 17.5D is not congruent to any of them because Figure 17.5B can be obtained from Figure 17.5A by swapping the position of R_2 with R_4 and R_1 with R_3. By rotating Figure 17.5C by 90 degrees towards left, Figure 17.5A can be generated. However, Figure 17.5D cannot be transformed into Figures 17.5A, 17.5B, or 17.5C.

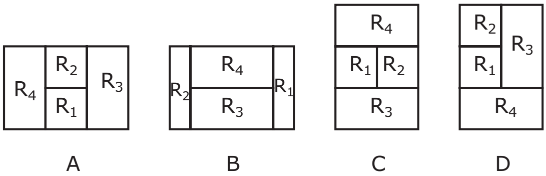

Figure 17.5
Explaining the concept of congruent rectangular floor plans.

By considering the definition of congruent floor plans, we can easily conclude that the rectangular floor plans generated by the C-RLAB algorithm are non-congruent to the rectangular floor plans generated by the spiral-based algorithm given in Shekhawat.[13]

Discussion

The current work is part of a larger work aimed at exhaustively exploring the use of rectangular arrangements in the design of layouts. We chose to work with rectangular arrangements because most architectural solutions still use this type of compositional schema. According to Steadman,[14] they do so because the rectangular packings offer the best flexibility of dimensioning (the flexibility allows any configurations of rectangles irrespective of their sizes; further it allows the assignment of different dimensions to those configurations, while preserving their rectangularity). Our goal is to provide architects with design aids, that is, algorithms that can generate good candidate solutions, taking dimensional and topological requirements into account, which can be further improved and adjusted by them, to provide a better solution to the user. These aids would be particularly useful in the design of large buildings with complex and specialized programs like hospitals.

Acknowledgement

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CHAPTER EIGHTEEN

RELATIVE POSITIONING

MIKE MCKAY

Introduction

How we understand the world is directly affected by our position in it. Constellations are simply the result of cognitive alignments related to our location in the universe, the horizon simply based on proximity and time. Relative Positioning explores the power of position in architecture: specifically, how anamorphic projection and perspectival techniques can generate space and challenge our understanding of its form. Architectural illusion and perspectival deceptions have been investigated since antiquity in order to alter the perception of a given space, primarily used in an illusionary or optical manner. However, anamorphic projection offers the potential to create dynamic spatial experiences that go well beyond simple projections or images/ shapes simply painted onto a surface. Within Relative Positioning, architectural form exists in three dimensions (real, physical) but is perceived via procession and emergent perceptions based on choreographed alignments and foci—making it possible for a duality of visual perception to occur. Much like the diagonal movement through Villa Savoye or the space created by Matta-Clark's cut, views and alignments add value, create perceptual shifts. One no longer views the architectural form as a whole, but as a collection of cinematic moments, serial form: a tension of object-qualities that elicits spatial ambiguity that puts pressure on the "real" and opens up a world of wonder and excitement.

> *The word 'anamorphosis' comes from the Greek: ana—'back,' indicating a return toward—and morphe—'form'—and is defined as a projection of forms outside their visible limits. Viewed from a precise vantage point (the convergence point of a geometrical construction), the distorted image recovers a recognizable form, and, as has often been observed, the projected image seems to lift up from the actual surface of the anamorphosis itself.*[1]

Background

Early cave paintings from Chauvet and Lascauex reveal a sense of wonderment and thought that are animated both by the content of the paintings but also the contours on which the paintings fall. The undulating walls of the cave and the play of light and shadow must have produced a powerful effect to those that created and observed the work. In some cases, the animals were depicted with multiple legs or heads in various positions not only to imply motion but to activate a real perception of movement. As the observer moves throughout the cave, the changing form due to the undulating walls adds to the sensation of motion, becoming cinematic. These early "projections" not only questioned humankind's place in the world but also provided one of the first examples of how humans saw that world. Although not directly intended to be "anamorphic," these paintings are the first to establish a point of view and with it a new understanding of place and time.

General ideas of using scale to imply spatial depth have existed since the 5^{th} century BC but it wasn't until the early Renaissance that painters began to experiment with these techniques to create a single, more unified theme rather than a collection of various scenes.

Brunelleschi, Bramante, Michelangelo, and other artists, began to experiment with this intuitive perspective but it wasn't until decades later that Alberti developed a mathematical basis for linear perspective. This new method allowed the observer to experience the work as an engaged participant rather than just an observer. "Linear perspective, as first developed in the Italian Renaissance, produced a centralized disembodied viewpoint and subject position analogous to what the seventeenth-century French philosopher Rene' Descartes called the 'mind's eye.'"[2]

Born from studies in corrected perspective, 'anamorphosis' became a technique that highlighted a singular point of view where an image would be revealed as one moved past the painting or through an architectural space.

In DaVinci's Codex Atlanticus, we find one of the first examples of an anamorphic drawing. DaVinci experimented with this technique to develop a method to correct or compensate for natural distortions in one's visual field. His experiments with optical vision and artificial perspective led to a general understanding of what we now call 'anamorphosis'. Around this time, there is also a small but significant use of 'anamorphosis' by

Piero della Francesca in his work Virgin with Child Saints and Angels from 1474. In this painting, there is an oval-shaped form painted ‘anamorphically’ so that when viewing the work from the desired point of view the oval form becomes a perfect circle. ‘Anamorphosis’ was later mathematically refined in 1663 by Jean Frabcois Niceron who was able to develop anamorphic images using a geometric key that utilized a foreshortened distance point method.

In most cases, the early examples of ‘anamorphosis’ were produced as a means to hide objects and symbols in painted works. The most famous of these hidden paintings is found within The Ambassadors painted by Hans Holbein in 1533. In this iconic work, an anamorphic scull is hidden at the bottom of the painting. Viewed frontally the scull is distorted and unrecognizable, but when viewed at an oblique angle and from the side of the painting, the image comes into focus. Following this, from Hoogstraten’s anamorphic boxes to the scientific work of Adelbert Ames, ‘anamorphosis’ evolved into a method of sensory experience where the relationship between the observer and the subject was becoming blurred. Within art, philosophy, and science, the role of the observer was becoming increasingly poignant. Focus was shifting from the subject toward the observer and their experience viewing a painting or architectural space. These ideas are apparent in Cubism, Dada, and Surrealism, and continue with the contemporary work of Felice Varini and George Roussee, as well as James Turrell and Robert Irwin, whose work focuses on the immersive and atmospheric qualities of the environment. While the project includes the investigation of surfaces that toggle between the perception of 2 and 3-dimensions (an investigation of flatness and surface as much as the construction of spatial depth), anamorphic projection techniques in architecture offer the potential to create dynamic spatial experiences that are 3-dimensional and go beyond simple projections; more than images/shapes simply painted onto an architectural surface, or even 3-dimensional artworks and installations.

Relative Position, by its “nature”, is an architectural investigation that demands one to move beyond these singular moments to a totality of space that is ultimately choreographed by “the other.” The physical inhabitation of space (what the surface alone can never offer) means that the participant is free to move from the “designed” cone of vision, a realm that actually dominates one’s time spent within the building or landscape. It also means that unlike Kuleshov’s experiment[3] and Eisenstein’s cinema,[4] architecture is in large part driven by programmatic considerations, addressed by the design of fundamental elements (stairs, ramps, apertures for light).

The need to satisfy the functional, programmatic requirements architecture demands becomes both the trigger and the beneficiary of the anamorphic system, as this realm is where effects such as color and reflectivity serve to smooth the seam of spatial transition between multiple cones and foci that overlap, collide, and contribute to a whole much larger than any single vantage point.[5] As an architectural work, this is also where the project both shares with and differs from other contemporary investigations and artists, such as Felice Varini who states:

> *My concern is what happens outside the vantage point of view. Where is the painting then? Where is the painter? The painter is obviously out of the work, and so the painting is alone and totally abstract, made of many shapes. The painting exists as a whole, with its complete shape as well as the fragments.*[6]

Yet, who goes on to add that his work "is not born to create specific shapes that need to satisfy the viewer." Within Relative Positioning, the satisfaction of programmatic and architectural needs is precisely what determines the design of the 'anamorphology' as a system that seams the various worlds of function and perception therein. In this way, the potential of the architectural exploration by nature exceeds the possible impact of tromp l'oeil and other "tricks of the eye:" the project examines the generation and perception of physical space experienced across time, where transitional spaces enter the conversation in their own right, with their own effects and impacts outside of any "content" conveyed at the moments of greatest alignment (i.e. a number, machine gun, circle; the image/icon with political, cultural import).

Relative Positioning

Digital 3D modeling tools such as Rhino allow for precise construction via the viewport where all spatial and formal effects can be tested from within the software (lighting, reflectivity, parallax, etc.). By using this process to make space, a reading of space emerges that is both real and perceived. The forms exist in three dimensions (real, physical) but are perceived via procession and emergent perceptions. Technically, forms are either projected to the point of the viewer or objects within the space are positioned along and within the perspectival cone that causes a change in scale and, depending on the point of view, a shift in relation. By using both of these methods, forms come into alignment as one moves closer to the focal point. Here, the cone of vision becomes an essential element within the generation and experience of architectural space. That digital tools offer the ability to calculate and visualize this cone is not a matter of convenience as much as further recognition that the perception of both visual and physical space relies heavily on the mechanics of the eye. What the cone of vision offers is a boundary within which one can play or challenge in terms of the design and construction of form and space. While the moments of greatest alignment may intend to communicate (meaning/message/content), as did the traditional "classical gaze," the project simultaneously capitalizes on the cone of vision as an ever-changing field, dependent upon the participant's chosen path.

Openings within surfaces are created by cutting along the line of the viewport projection and then scaling points or surfaces to the Viewpoint (a.). Since the first reference point of scaling is the Viewpoint, there is no distortion within the surface thus maintaining the implied shape/form regardless of the distance from the viewer. Therefore, moments of greatest alignment are not the culmination or "punch line" of the experience, but rather the set-up or touch-point for another "main event" that is just as important: the experience and challenge presented by the "non-aligned space," the space between these punctuated moments of visual, geometric clarity, and "content."[7] This is not a traditional formalist endeavor but rather the form is a direct result of relative positioning as one moves through the space, where views of fragmented and continuous space add to one's sense of spatial ambiguity.

Since the spaces created have multiple focal points, and forms might share multiple foci, the space is constantly vibrating based on the viewer's proximity to the focal point—a visual flipping or slippage. The object(s) of form are constantly changing according to the adjacencies of other formal objects and the point of view of the observer. In this sense, both physical and virtual object-forms are created that allow for a new experience of the space.

By perceiving the alignment of determined form and the subsequent disjunction of that form, one is able to participate in the spatial experience rather than simply "viewing" it. In this sense, movement through the space is animated and the subject/object relationship is questioned. It enables one to be an active participant within 'spaceforming' and convey a sense of sensation that a "static" space cannot.

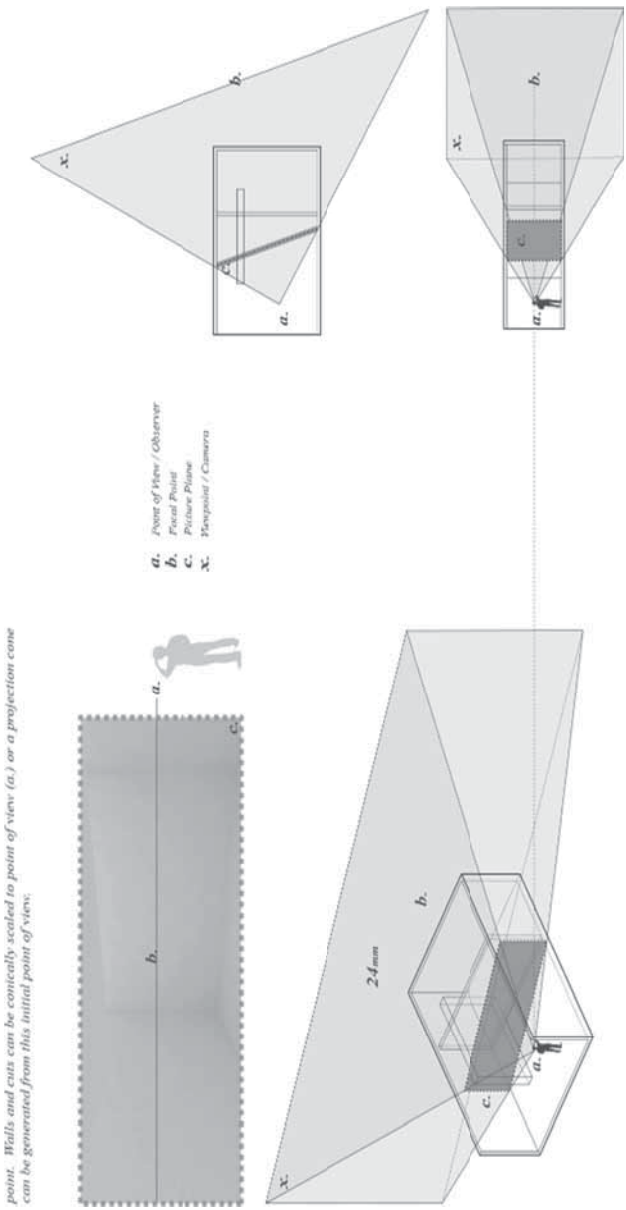


Figure 18.1
Relative Positioning—Description.

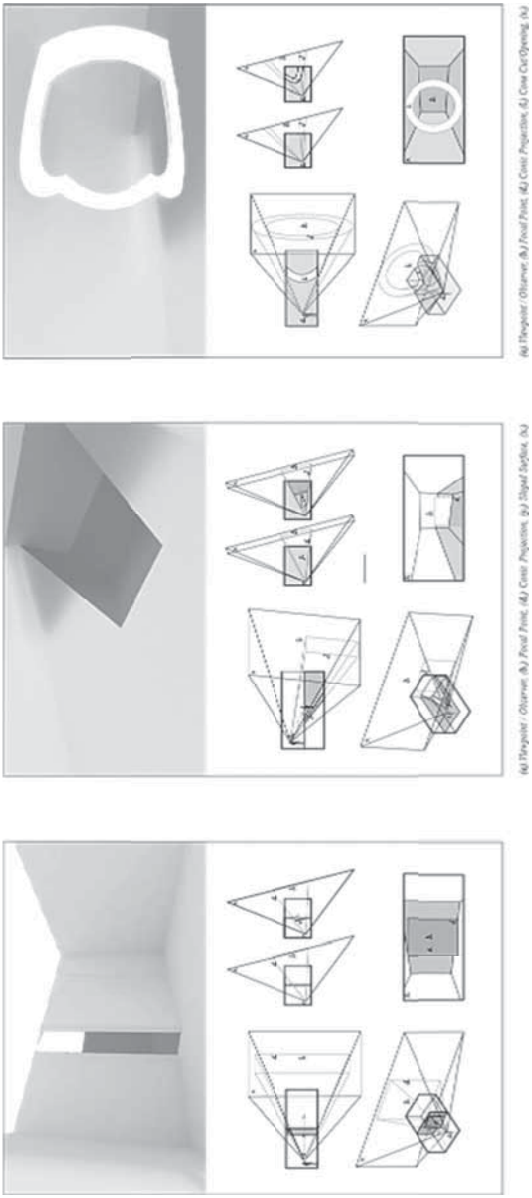


Figure 18.2
Relative Positioning—General Concepts.

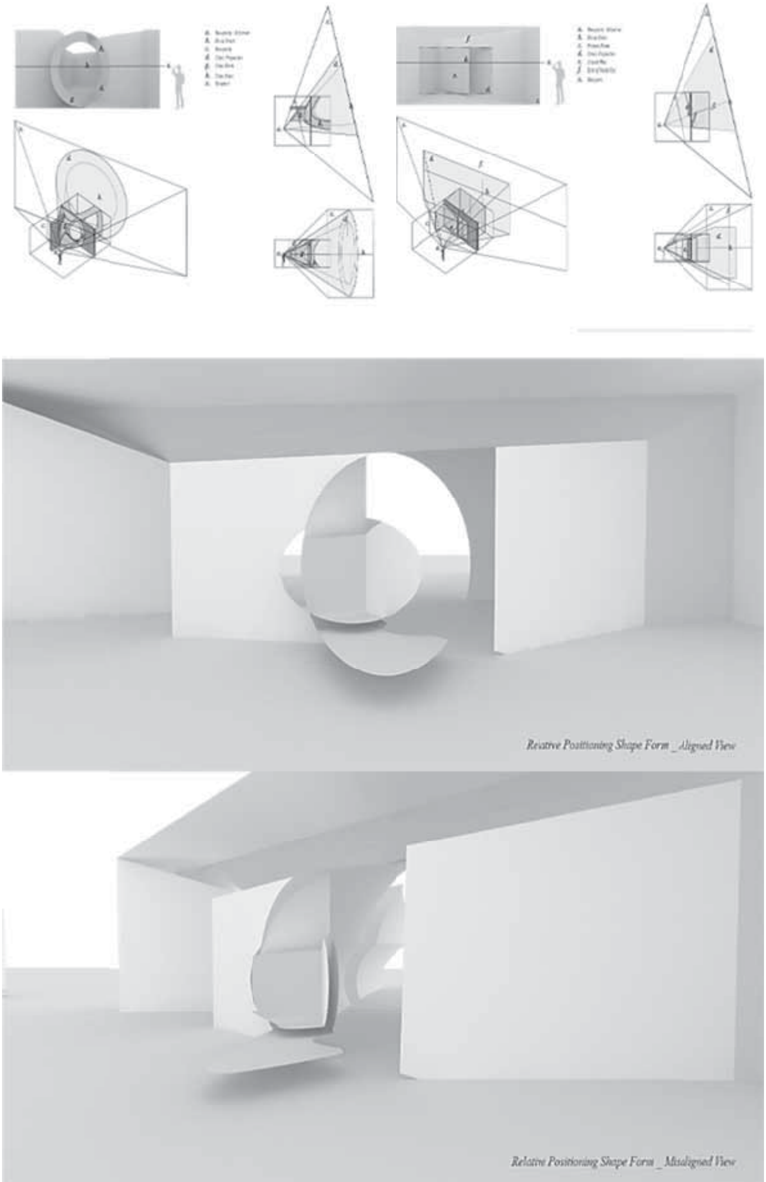
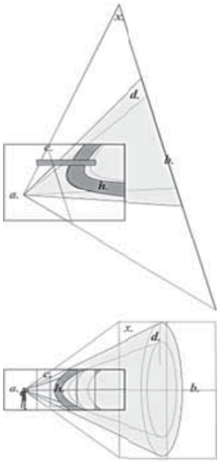
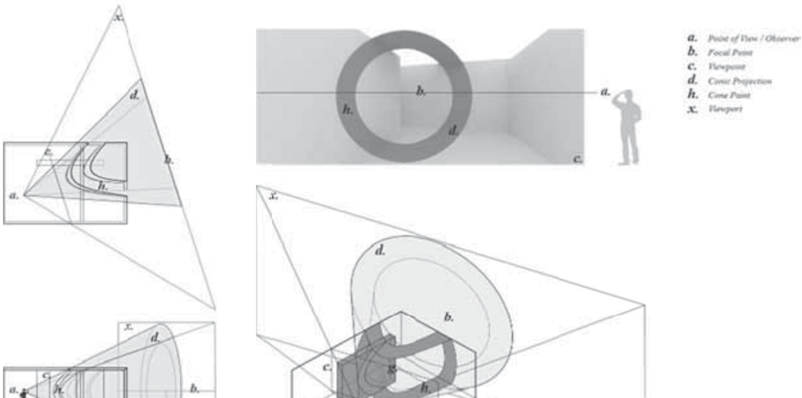


Figure 18.3
Relative Positioning—Projection Cone Form and Scale.

An architectural space made be constructed using the point of view of an observer. Once this point is established, any manipulation to the space is relative to the position of that point. Walls and cuts can be conically scaled to point of view (a.) or a projection cone can be generated from this initial point of view. Circulation and openings within surfaces are created by cutting along the line of the viewport projection and then scaling points or surfaces to the Viewpoint (a.).





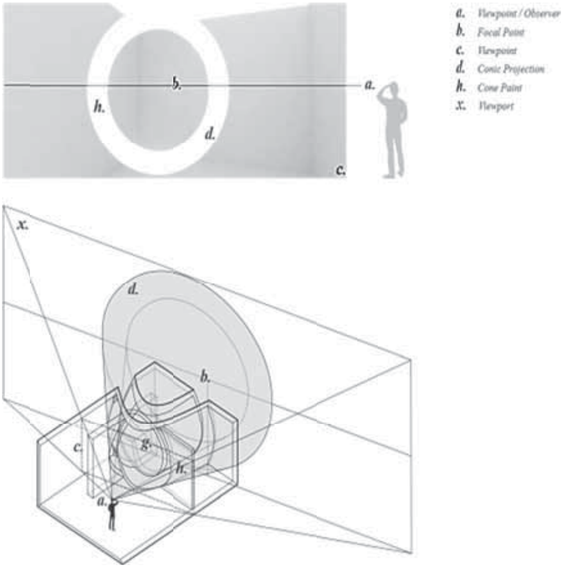


Figure 18.4 (previous page and this one)
Relative Positioning—Projection Cone Split and Projection Cone Cut.

The Projection Cone Form may be used to define walls and cuts within the space as long as manipulations are controlled from the Viewpoint (a.) and the initial shape form remains intact. Openings within surfaces are created by cutting along the line of the viewport projection and then scaling points or surfaces to the Viewpoint (a.). Since the first reference point of scaling is the Viewpoint there is no distortion within the surface thus maintaining the implied shape/form regardless of the distance from the viewer. The projection cone may be used to split surfaces within in the space in order to define a change of material. This 2 dimensional technique is used in conjunction with other Relative Positioning techniques to heighten the spatial experience. Once split by the projection cone shape, surfaces within the space can be removed or manipulated in order to create openings. These openings can be used for passage and light. In addition, these cuts make it possible to simultaneously experience the space of the projection and the spatial distortion created by the cuts. It is not necessary to use an image to project through the space. Relative positioning can be achieved by manipulating the context or new forms using the point of view. It is possible to 'cloak' elements within a space by projecting the forced perspective lines onto surfaces. In addition to the lines, use of color, material, and lighting make it possible for surfaces to 'disappear'.

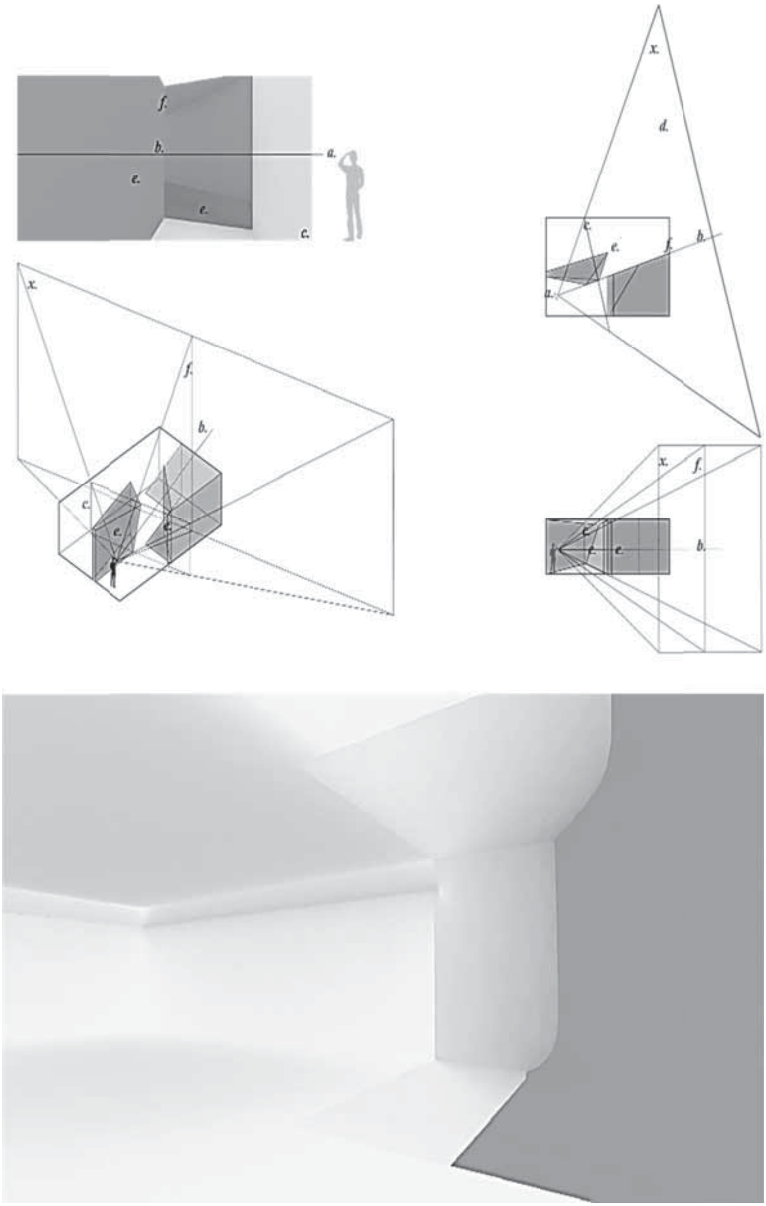
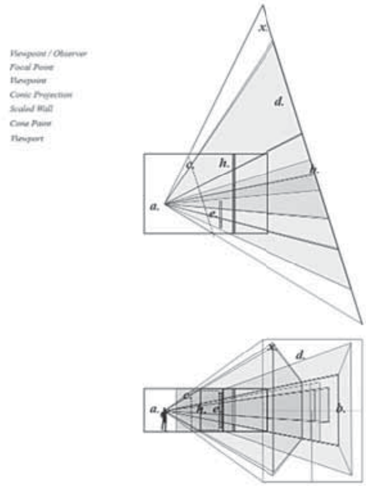
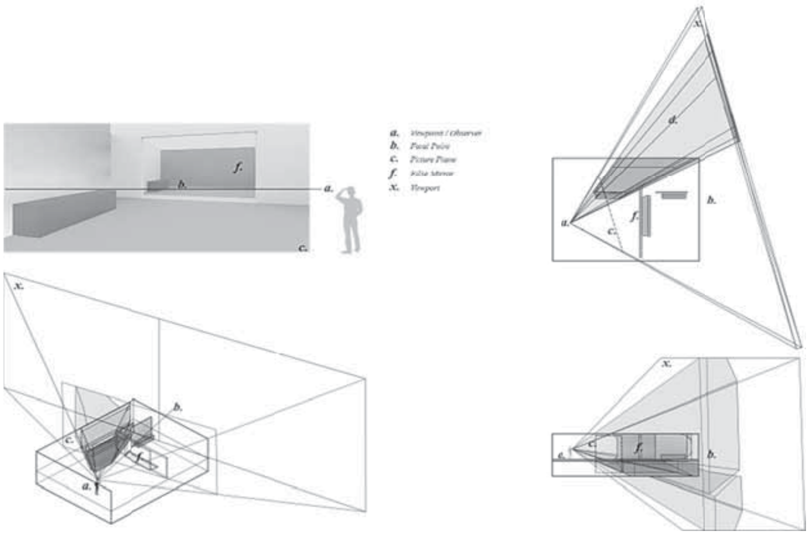


Figure 18.5
Relative Positioning—Context Manipulation.


Viewpoint / Observer
Focal Point
Viewpoint
Conic Projection
Scaled Wall
Cone Point
Viewport


a.
b. Focal Point
c. Picture Plane
f. False Mirror
x. Viewport

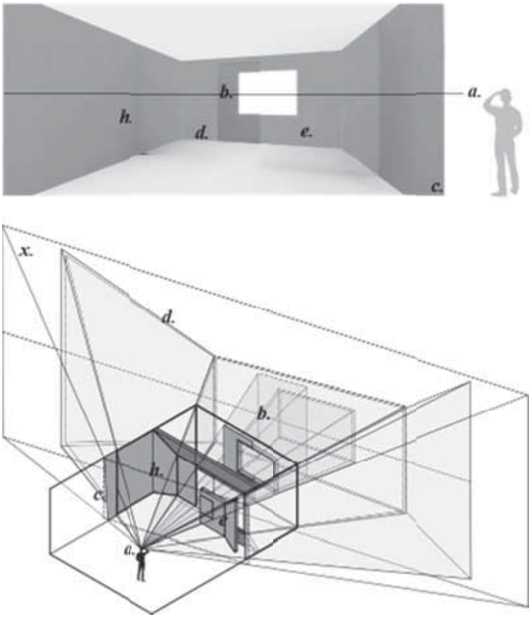


Figure 18.6 (previous page and this one)
Relative Positioning—Mirror and Cloaking.

Discussion

The apparent flattening of space through material qualities and the formal techniques of Relative Positioning make it possible for a duality of visual perception to occur, the emphasis is not illusionistic, but immersive through the act of peripatetic seeing.[8] In this respect, the project doesn't seek to "trick" the eye, but to elevate an awareness of the space that is beyond the physical—to draw the eye forward and, through its own expectations, in essence to offer up to the eye more than it originally anticipated: a sensual and cerebral environment within which to dwell. Here, the form is a product of spatial shifts, a parallax effect where forms (and material effects) come in and out of focus and exist as part of a larger collection of experiential moments, where movement through the space activates both conditions (aligned and non-aligned) without predetermined, linear sequence. These tensions of object-qualities elicit a spatial ambiguity that puts pressure on the "real" and opens up a world of wonder and excitement. We become participants in this new environment. Here, it is OK to question where illusion is physical and ambiguity is desired. This is a new form of collage.

Notes

1.Anamorphosis, An Annotated bibliography, Perez-Gomez and Pelletier.
2. Lyle Massey, "Anamorphosis through Descartes or Perspective Gone Awry," *Renaissance Quarterly* 50, No. 4 (Winter, 1997): 1148-1189. "Not only does perspective fail to conform to a Cartesian model, it even contradicts it in many ways. Early modern artists and mathematicians struggled to relate geometry to representation and vision to space and in the process they gave visual form to a split between mind and body."
3. Lev Kuleshov was a filmmaker from the 1910's and 1920's who experimented with the relationships between imagery and one's implied meaning through juxtaposition.
4. Sergei Eisenstein, *The Eisenstein Reader,* ed. Richard Taylor, Trans. Richard Taylor and William Powell (London: BFI, 1998).
5. Mike McKay, *Seaming,* Master's Thesis, Princeton University, 2005. "The thesis explores the tension between two methodologies by generating a specific collision of initially autonomous programs within the restriction of a given frame. Focusing on the consequent spatial conditions that arise from this intersection, the project seeks to question our alternating perception of the fragment and/or whole via methodological strands that represent these two polar attitudes: disjunction (fragment-philic) and smoothing (fragment-phobic)."
6. Felice Varini, *I am a Painter,* Interviewed by Dr. Gil Dekel, 2008.
7. Yve-Alain Bois, "A Picturesque Stroll around Clara-Clara", *The MIT Press* 29 (Summer 1984): pp.32-62. "We know that Eisenstein disagreed with Kuleshov (and others) on one fundamental point: he did not want montage, the experience of shock, to involve only "the element between shots," but wanted it to be "transferred to inside the fragment, into the elements included in the image itself."
8. Bernard Fibicher, *Common Places and Particular Perspectives*. "In this context it is not the work as such that would interest us, but rather the path toward the work, our pathfinding toward the point of view. The study of the figure / ground antinomy would have to be replaced by an analysis of the process of figuration.", http://www.varini.org/04tex/texa04.html.

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Lyle Massey, "Configuring Spatial Ambiguity: Picturing the Distance Point from Alberti to Anamorphosis," *Studies in the History of Art* 59, Symposium Papers XXXVI: The Treatise on Perspective: Published and Unpublished (2003): 160-175.

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Colin Rowe and Robert Slutzky, “Transparency: Literal and Phenomenal,” *Perspecta* 8 (1963): 45-54.
Tomás García Salgado, “Anamorphic Perspective & Illusory Architecture,” Paper presented at Generative Art International Conference, 2001, http://www.generativeart. com/salgado/anamorphic.htm.

CHAPTER NINETEEN

TYPOLOGICAL TRANSFORMATIONS IN A SAME SHAPE

TERESA LEITE, ANA COSTA AND ELIANE CONSTANTINOU

Introduction

The analysis of social interest projects developed by SP Group, from São Paulo, Brazil—House in Luanda (2010) and Green Housing in Brasília (2011)—draws attention to their similarities. We may highlight the similarity of formal arrangement of both basic housing units, as well as the organization and space distribution inside them, suggesting the adoption of the same typological scheme in both projects.

The main goal of the following analysis is to analyze, comparatively, how the same typology addresses different project problems imposed by different contexts.

The project House in Luanda is a response to an international contest launched by the Lisbon Architecture Triennial 2010/2011. The bases of the competition establish the design of a low-cost patio-house located on a flat area near the city limits of Luanda.[1] The Green Housing in Brasília, specifically in Vila Planalto, responds to a Latin American contest—Holcim Awards—that seeks to encourage the development of sustainable and innovative constructions that are focused on the future.[2] Both projects were never built. Although the two contests present specific demands and distinct assumptions, SP Group chooses to approach a common subject: social housing. In these cases, they propose houses that are defined by the spatial articulation, in one or two floors, of a standard module.

The Universal Cell "H" and its Extensions

In the proposals developed for Luanda and Brasília, one can notice that in two rectangular prisms we have the dry areas. Social and intimate sectors are apart, each one in a prism. Another two smaller sized geometrical rectangular prisms shelter the wet areas: the kitchen and the bathroom.

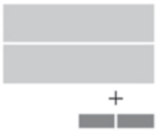
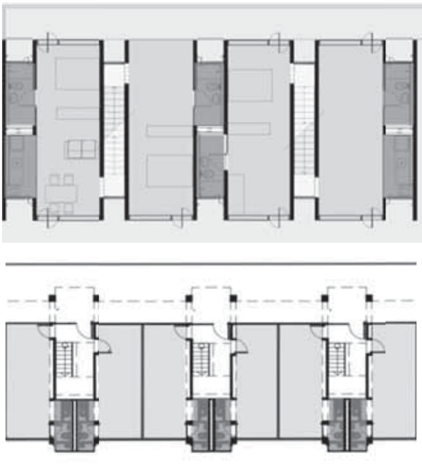


Figure 19.1
Identification of pure volumes that compose both projects.

In this regard, it is important to notice that other Social Housing projects, developed by SP Group, are also organized through the articulation of a pattern module or a "universal cell," as in the Cônego Vicente M. Marinho Group of apartments (2004) and the "CAIXA" project (2004), both in São Paulo. In these cases, the cells multiply vertically, shaping buildings in height and are defined by the articulation of a prism with free plan and another secondary prism, with wet areas (Figure 19.2).



(a)

(b)

Figure 19.2
(a) "CAIXA" basic cell (2004); (b) Cônego Vicente M. Marinho group of apartments (2004) basic cell.

By decomposing the form, one can observe that the formal strategy is a juxtaposition of volumes. At each dry volume it is juxtaposed a smallest volume that contains the wet area (Figure 19.3[a]). The two volumes, now composed, stay parallel, face-to-face and the space between them sets a semi-private patio, pointed in yellow in Figure 19.3(c). A connecting element between the two resulting volumes is added to the composition (Figure 19.3[b]) setting the final form shaped "H" (Figure 19.3[c]). This element creates the access areas and connects the block headed to the intimate areas (red) and the block headed to social and service areas (orange and yellow) (Figure 19.4). These areas are strictly related to the central patio, to where all the rooms open themselves through glazed panels. It works like a natural extension of all ambiences.

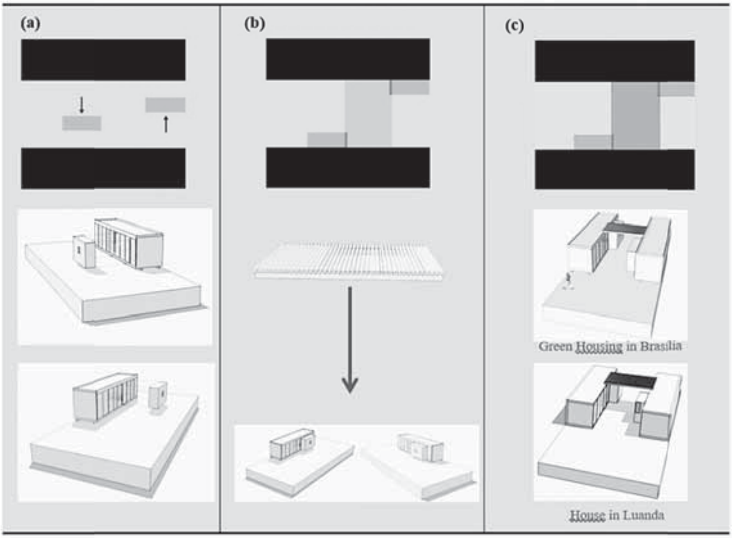


Figure 19.3
(a) Juxtaposition of volumes; (b) Connecting element in red; (c) final shape.

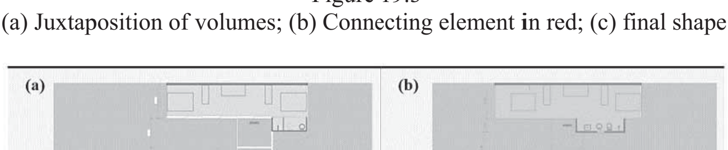


Figure 19.4
(a) House in Luanda (2010); Green Housing in Brasília (2011). Group SP.

The interior of the house is characterized by non-partitioning of the space; the only existing walls are the exterior ones. Both blocks have a free plan and a circulation developed in their periphery (Figure 19.5). However, the spaces that require privacy, like bedrooms, are suggested by the furniture. In the resulting layout, one can observe that each cell has a maximum capacity of five people, considering two people by each double bed, and one by each single bed.

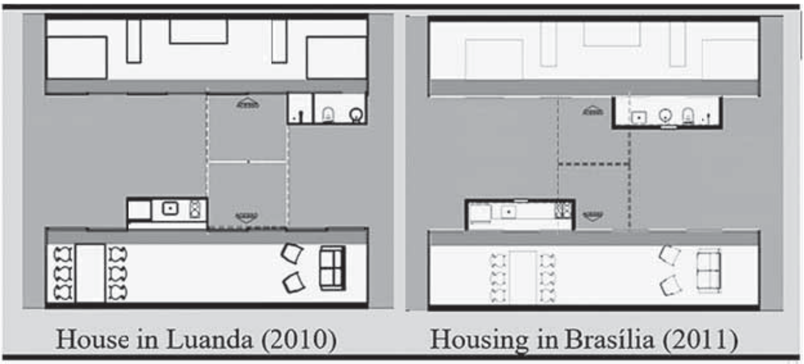


Figure 19.5
Peripheral circulation.

To make a spatial analysis, one must consider that these are small-sized houses (Luanda 26,25m^2 and Brasília 33,75m^2 covered area)—in which small subtleties set big changes. In Luanda, the double bedroom is configured as a suite with a private bathroom. However, as the construction of another bathroom in the cell is not expected, the peripheral circulation that connects the dorms to the bathroom compromises the privacy of that room (Figure 19.6[a]). On the other hand, in Brasília, the bathroom is slightly displaced, and its access door aligns with the wardrobe, shaping a neutral entry, ensuring more privacy to the room (Figure 19.6[b]).

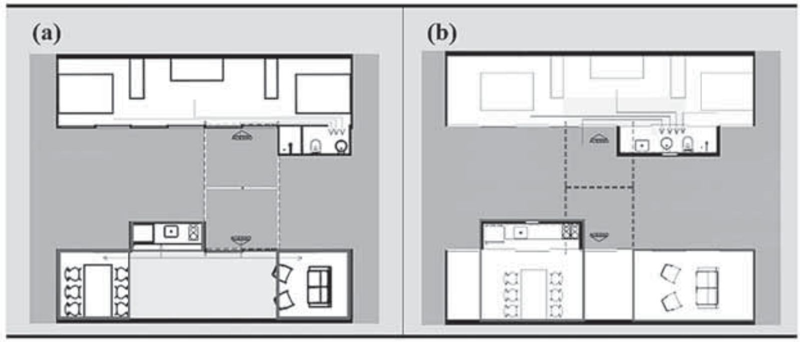


Figure 19.6
Spatial analysis.

In both projects, a more confined double room exists—it is not necessary to cross it to access to another room. On the other hand, the centralized position of the "single room" compromises its privacy. In the social block, the position of the kitchen also changes.

In Luanda, the kitchen relates to an undetermined space that merges with the circulation (Figure 19.6[a]). In Brasília, the location of the kitchen articulates best with the dining area, setting two areas: kitchen/dining and living (Figure 19.6[b]). We observe that the cells address the basic demands of living: sleep, sanitize and perform basic needs; prepare meals; eat and live. To account for the needs of future expansions, as an extra room or space work, the designs incorporate different strategies.

In Luanda, the addition of a block juxtaposed transversely on the previous blocks is predicted, with staircase aggregation in the central courtyard, which allows the vertical transition. The housing unit is now organized on two levels (Figure 19.7[a]).

In Brasília, we witness a dismembering of "H." The prisms corresponding to the social and intimate sector no longer need to be parallel front-to-front, and are now able to slide on the ground. Often, the connecting element between both volumes that existed in the base form "H" disappears (Figure 19.7[b]). There is a new smaller block that comes from the reconfiguration of the intimate block (Figure 19.8[a]). The position of this new composite element is relatively flexible: parallel or perpendicular to the other blocks (Figure 19.8[b] and [c]).

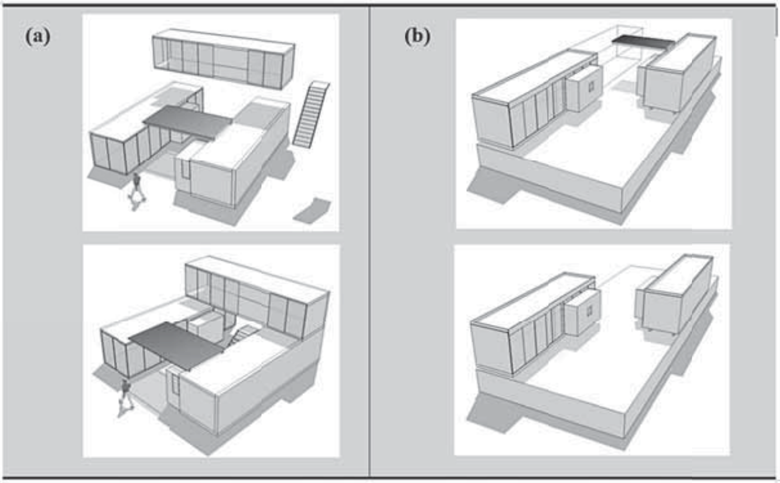


Figure 19.7
Third moment (a) House in Luanda (2010); (b) Green Housing in Brasília (2011).

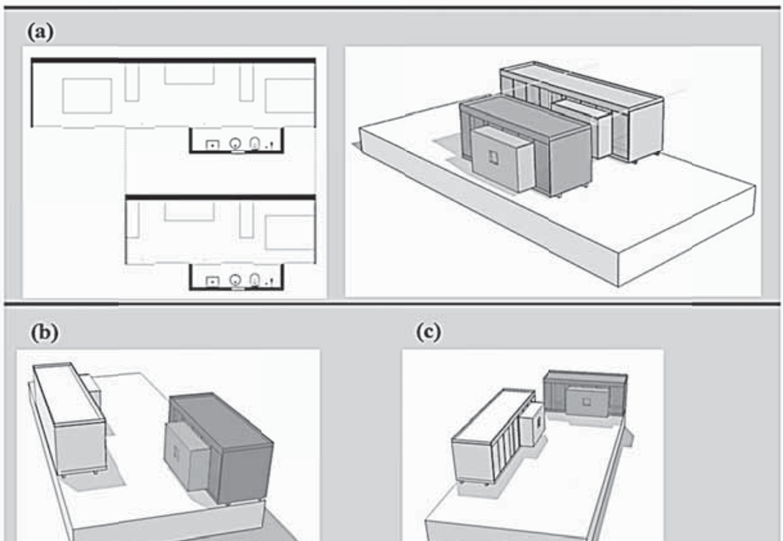


Figure 19.8
Green Housing in Brasília (2011).

Analysis of the Modulation of the Cell

The planimetric analysis reveals distinct grids in both projects. In Luanda, the modulation of 4x4m organizes the unit. Two parts are construction, and two are courtyard (Figure 19.9[a]). One grid of 2,5x2,5m designs the form, the location of the humid blocks, the proportion of the patio, and the placement of the furniture (Figure 19.9[c]). In the third moment, another prism is overlaid, and it is also contained in this grid. The design of the humid block occupies half module (Figure 19.9[c]). Thereby, the project respects, in its entirety, that modulation.

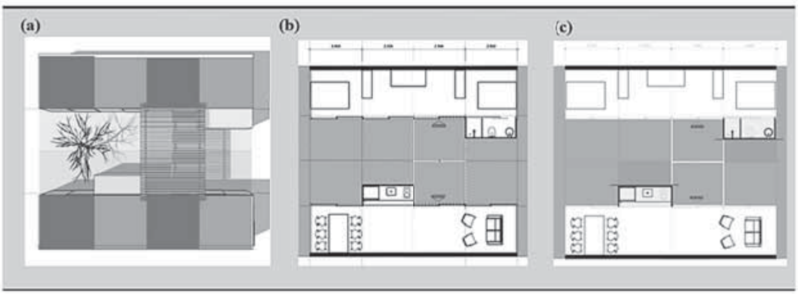


Figure 19.9
Planimetric analysis of House in Luanda (2010).

If in Luanda the composition is guided by a modulation of 4x4m, in Brasília, the composition of 8x9m is ruled by modules of 1.25x1.25m (Figure 19.10[a]). This grid interferes directly in the volumetric composition, in the position and design of the humid blocks, in the furniture layout, and in the definition of the glazed facade design (Figure 19.10[b]). It is a symmetric project following two axes. The square A is a mirror of the square D; the square B is a mirror of the square C (Figure 19.10[c]).

Figure 19.10
Planimetric Analysis of Green Housing in Brasília (2011).

In altimetry, the house in Luanda preserves the grid of 2.5x2.5m. The grid is three-dimensional (Figure 19.11).

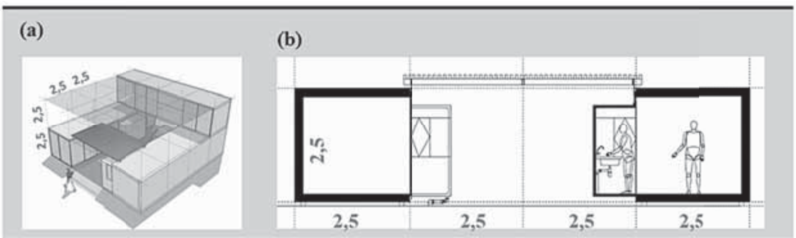


Figure 19.11
Altimetric analysis of House in Luanda (2010).

In Green Housing, in Brasilia, it is possible to see 1,25m as the three-dimensional rule, but only in the humid blocks (Figure 19.12). A three-dimensional rule doesn't exist.

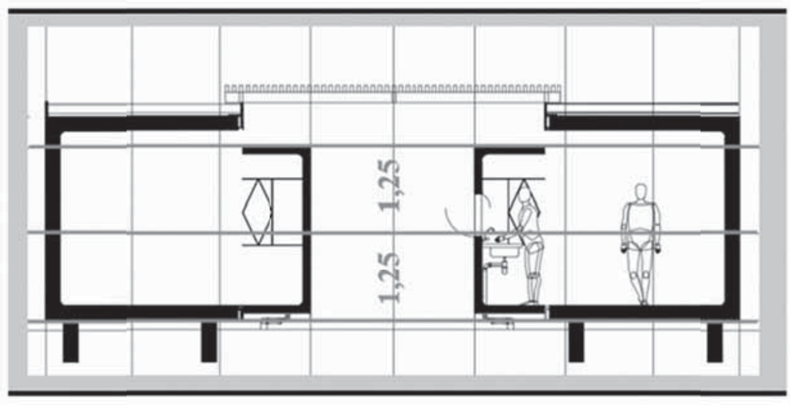


Figure 19.12
Altimetric analysis of Green Housing in Brasília (2011).

The modular design indicts the use of prefabrication, as verified in both projects. It is predicted the prefabrication of a precast concrete C (Figure 19.13[a]), with the measures 10x2.5x2.5m in Luanda and in Brasilia 2.75x2.75x11m. On site, the concrete C is juxtaposed (Figure 19.13[b]) and in Luanda can be stacked (Figure 19.13[c]).

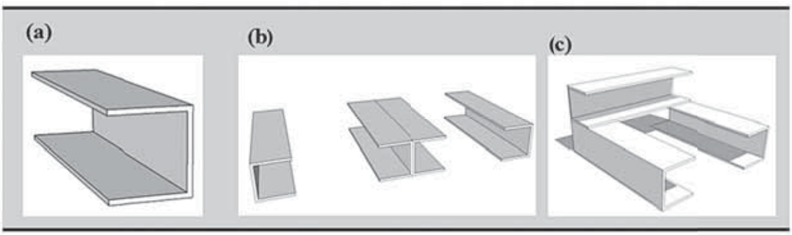


Figure 19.13
(a) Precast concrete C; (b) Juxtaposed structures; (c) House in Luanda (2010).

Openings and Solar Orientation

In both projects, we observe that the treatment of the facades favors the physical and visual relation of the ambiances with the central courtyard, instead of the solar orientation impositions. This way, in the interface with the patio, the prisms are sealed by a single glazed surface, which is opposed by the blind treatment of the other faces. The element of connection between the two prisms has also partial shading functions (Figure 19.14).

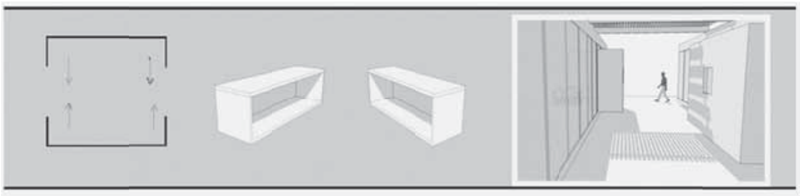


Figure 19.14
Facade and central courtyard in House in Luanda (2010) and Green Housing in Brasília (2011).

One modulation of 1.25m rules the squareness of both projects: in Luanda, eight sliding frames and, in Brasília, nine window frames. The facades of both projects differ in the location of the hydraulic block. They also differ in the hydraulic blocks. In Luanda, there are two opposed openings in the side walls of each hydraulic block and, in Brasília, there is just one window in the facade facing the patio. In Luanda, in the dry blocks, the design of the openings is free from the prefab concrete structure. According to the solar orientation, the opening or closing of the side planes is anticipated, as well as the roll-back of the glass surfaces from the shape limits, improving its shading (Figure 19.15).

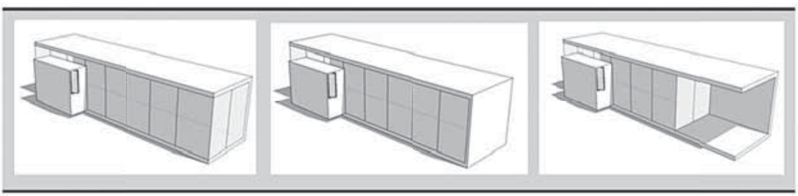


Figure 19.15
Possible opening of House in Luanda (2010).

Cell-Site

—Lot—

In House, in Luanda, the lot isn't defined, described only as "a flat plot in the outskirts of Luanda" .[3] It is proposed that the settlement of twenty-seven housing units is for approximately 135 people. The terrain is organized from the shape "H" of the base module. The blind facades of this module define the boundaries of the plots (Figure 19.16[b]). The units are juxtaposed in the land—two consecutive blind facades—(Figure 19.16[c]) or interspersed (Figure 19.16[d]).

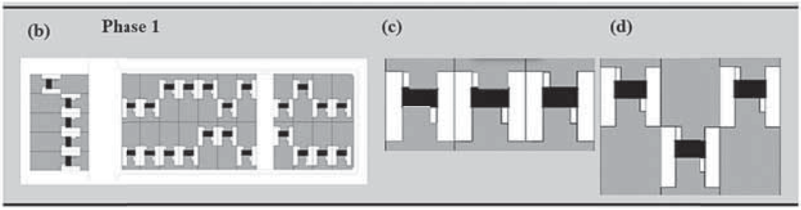


Figure 19.16
(b) Proposed organization; (c) Illustration of modular aggregation; (d) House in Luanda (2010).

This proposal is dynamic because, although it does not predict the increase of housing units, it considers the possibility of an increase of the density. The SP Group designs a possibility of evolution of urban network in three phases (Figure 19.17). We estimate that the population density may increase more than 70% (approximately from one hundred and thirty five to two hundred and forty inhabitants).

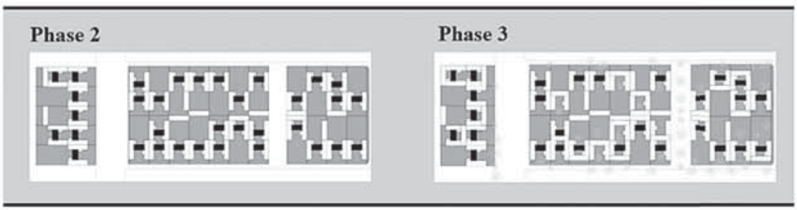


Figure 19.17
Possibility of urban network evolution, House in Luanda (2010).

The implementation of sustainable housing in Brasilia was planned in Vila Planalto, between Minas Gerais street, Brasília street, and Vlpa four and five streets (Figure 19.18[a]). A zone with a great view to the Paranoá Lake. The creation of approximately one hundred and seventy two residences was proposed, aggregated horizontally in a dynamic way. Although it doesn't have physical limits, a grid about the plan reveals—as in Luanda—the blind limits of the "H" rule for the distribution of the units in the field (Figure 19.18[b]).

Figure 19.18
Green Housing in Brasília (2011).

The form "H" displayed in the project as "base module" is used in only thirty-nine of one hundred and seventy two predicted units (Figure 19.19[a]). The dismemberment of the initial shape allows the resident to have some liberty defining the final plan of the house. Three scenarios are considered: the "H" is kept as a base (thirty nine units) (Figure 19.19[a]); the blocks slide on the field but the connection element is held (sixty nine units) (Figure 19.19[b]); the connecting element disappears (sixty four units) (Figure 19.19[c]).

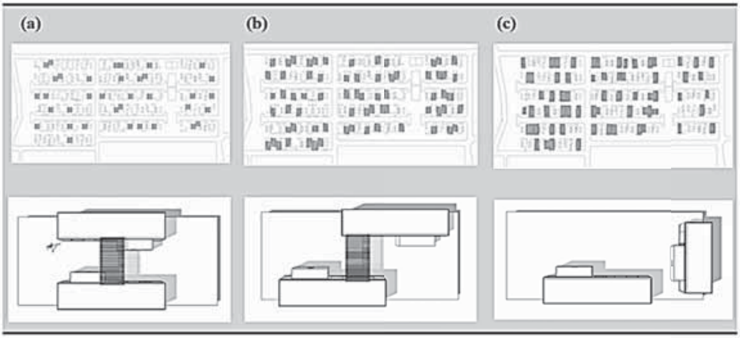


Figure 19.19
Units' distribution in the plot, Green housing in Brasília (2011).

In the suggestion of organization of the land, there is a very recurrent plot (thirty seven units) that belongs to the last group of situations where the connecting element disappears (Figure 19.20).

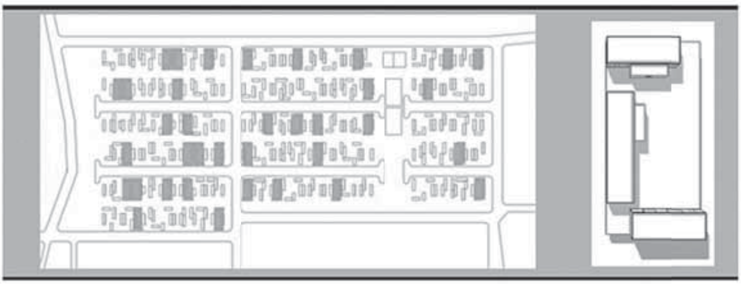


Figure 19.20
Organization type. Green Housing in Brasília (2011).

Relations between Units and Public Space

The way public space is organized is distinct in the two projects, as well as the relations between each unit and the scales of the interventions. If in Luanda the area is approximately 708m^2 in a plot with approximately 7440m^2, in Brasília it reaches 5805m^2 in a plot with approximately 65000m^2. The parceling of the land in Luanda defines three quarters, which geometry it's not strict (Figure 19.21[a]). The pedestrian and road circulations are usually peripheral, but there is an exception when the pedestrian circulation rips two ample paths between the houses (Figure 19.21[b]).

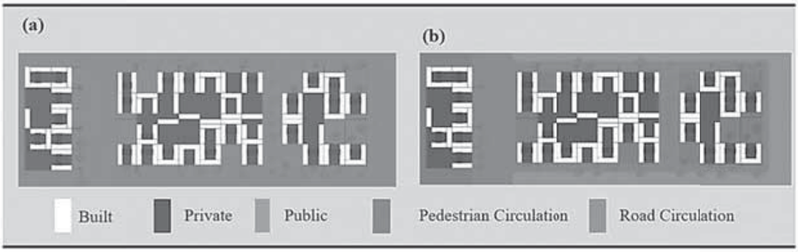


Figure 19.21
(a) Public/private; (b) Public/private and circulations system. House in Luanda (2010).

All the plots have immediate contact with a pedestrian path. The contact of the unit with the circulation can be done in three ways: a) the base cell immediately perpendicular to the circulation, allowing the access to the "interior of the quarter" by its center (Figure 19.22[a]); b) a block parallel to the circulation above the base cell (Figure 19.22[b]); c) base cell perpendicular to the circulation, retreated on the field (Figure 19.22[c]).

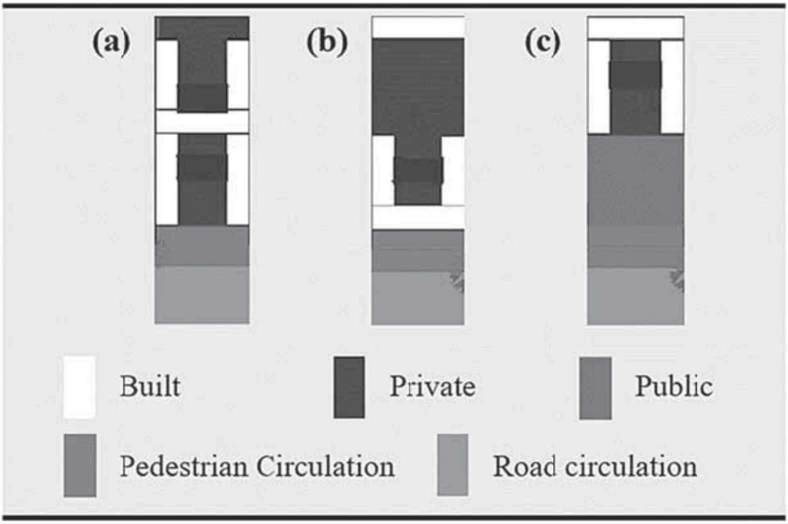


Figure 19.22
Relations of the lots with the circulation. House in Luanda (2010).

Despite that, the House in Luanda generates a pattern where it is possible to configure patios, the privacy of these is dependent on the neighboring lot configuration, as in the following example (Figure 19.23).

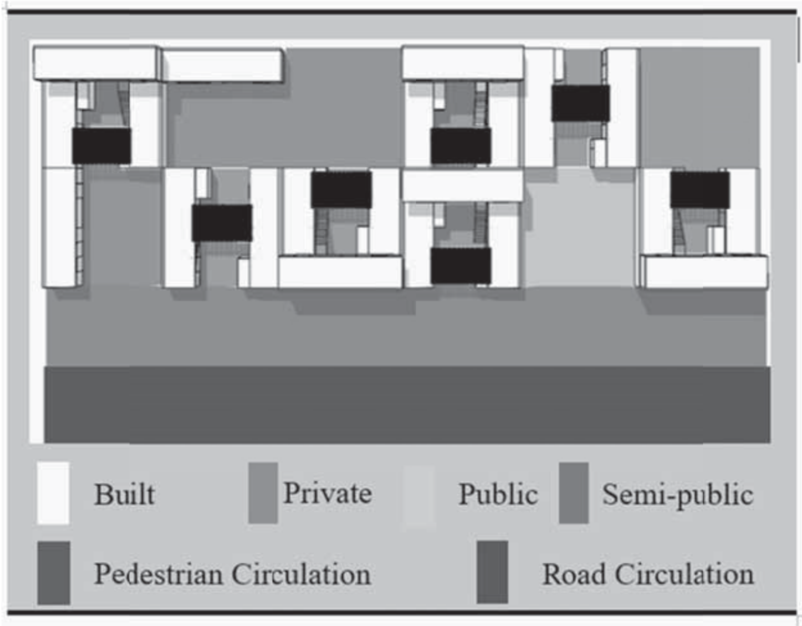


Figure 19.23
Private/public. House in Luanda (2010).

In Brasília, the interior of the quarter doesn't exist. The way the units are displayed in the field allows walking routes throughout the land that has not be built on (Figure 19.24). There are no physical barriers between the units.

The primary access roads are the ones that already exist in the city, peripheral to the terrain. From these accesses, two complementary systems are defined: collecting and connecting streets between the main roads; and service roads of housing units, which close in cul-de-sacs (Figure 19.24). The parking lot has no specific location, occupying residuals areas. Group SP designs a pedestrian circulation corridor, away from automobile traffic streets, that connects the plots to the public areas, where the creation of sports courts is predicted.

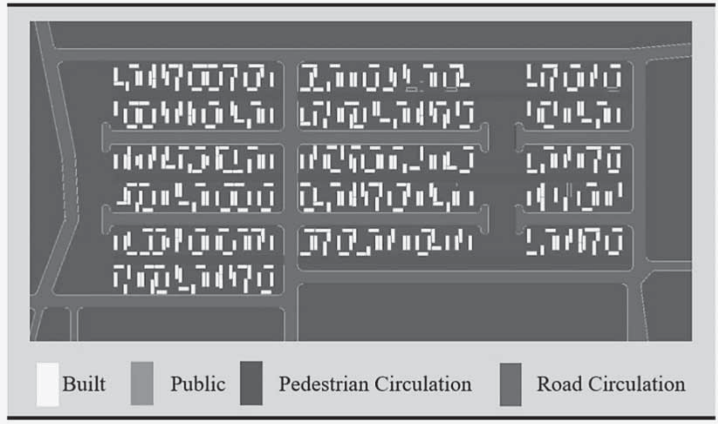


Figure 19.24
Circulation scheme. Green Housing in Brasília (2011).

The contact of the unit with the circulation can be done in many ways, due to the variation of configurations allowed. However, it is known that the unit will always have two fronts, one facing the street traffic and the other focused on pedestrian circulation. The introduction of green areas increases the settings of possible interfaces of the unit with peripheral circulations. Given the project extents, a zoomed sample is used to illustrate the various possibilities. Thus, the two cases set different privacy degrees. In Luanda, the units almost close in themselves, in Brasília, the public and private spaces blend, compromising the privacy of the units. This collectivization of space can be a design intent, as the SP Group's explicit references to Oscar Niemeyer's work in the definition of sustainable housing project in Brasília.[4]

Discussion

Similarities between projects are evident. There is also a typological relation between the unit's definition and other projects of SP Group. It is in urban analysis that the proposals are more different and where the distinct project's intentions are visible. In Luanda, the positioning of the units on the ground creates courtyards that, although open, configure intimate spaces; in Brasilia, it is the ideal community that is valued. However, both proposals respond to modern principles. In ancient cities, with roots before the modernism, the border between public and private is easily identified: the street and the square are the public spaces; the interior of the block is the private space.[5]

In the modern urbanism, space is collectivized, for all the people and all uses. It is this collectivization of space that we witnessed in both projects, although with a greater emphasis on the Brasilia project. One should take into consideration that these two projects start from the same base but the problems they propose to answer are distinct. Still, we can consider that there is an evolutionary process from Luanda to Brasilia, if we consider that Brasilia breaks the rigidity of the modulation, winning in spatiality in the unit and in flexibility in urban terms.

Notes

1. Sebastian Jordana, "A House in Luanda: Patio and Pavillion International Competition," 24 Feb 2010, ArchDaily, accessed on 15 May 2015, http://www.archdaily.com/50959/a-house-in-luanda-patio-and-pavillion-international-competition/.
2. “2010/2011 Hocil Awards for Sustainable Construction,” 2009, Holcim, accessed on 15 May 2015, http://www.holcim.us/en/sustainable-development/holcim-awards.html.
3. Sebastian Jordana, "A House in Luanda: Patio and Pavillion International Competition,” 24 Feb 2010, ArchDaily, accessed 23 June 2015, http://www.archdaily.com/50959/a-house- in-luanda-patio-and-pavillion-international-competition/.
4. ”Habitação Social em Brasília,” 2011, Grupo SP, accessed on 15 May 2015, http://www.gruposp.arq.br/.
5. Maria Luisa Adams Sanvito, “Habitação Coletiva econômica na arquitetura moderna brasileira entre 1964 e 1986,” UFRGS, Porto Alegre, Outubro, 2010, Page 199.

CHAPTER TWENTY

THE REVISION OF THE MASTER PLAN OF THE UNIVERSITY OF AVEIRO: A HETEROGENEOUS PLANNING MANAGEMENT

SÉRGIO MENDES

The Campus in 1987

The Campus of Santiago of the University of Aveiro is located in the southwest of the City of Aveiro, around the Diocesan Seminary existing in that location. The Bay of Aveiro confines it at the east and north by the City, in the south by the estuary of S. Peter, and by the Santiago Place in the west. The first plan of the University, henceforth designated by PGUAZ (Master Plan of the University of Aveiro: Zoning), whose main feature was to predict continuous buildings radiating from a central square, was abandoned by the Rectory of the UA in 1987 because it was not operational. Back then, it was important that the University rapidly obtain another type of plan that allowed the problem of the construction of its facilities to be quickly solved (attending the EU funds available at the time). Therefore, in that same year, a protocol with the team coordinated by Nuno Portas was established.

At the campus, only some of the buildings predicted in the original plan were then built, namely the Complex of the Central Square, the Integrated Centre of Teachers' Training, and, close to this, following the structure predicted in the plan, the Department of Electronics and Telecommunications, which included an isolated auditorium. There were still two projects: the one of the Department of Planning and Environment, and a First Students' Residence. A pragmatic and diversified process of urban management of the campus construction was thus initiated that has contributed to the posterior formulation, by Nuno Portas, of the theory on which he bases its current definition of "Urban Project," as we shall see.

Figure 20.1
Two drawings of the Revision of the Master Plan of the University of Aveiro. (Image courtesy of CEFA)

Figure 20.2
The City of Aveiro and the University Campus.

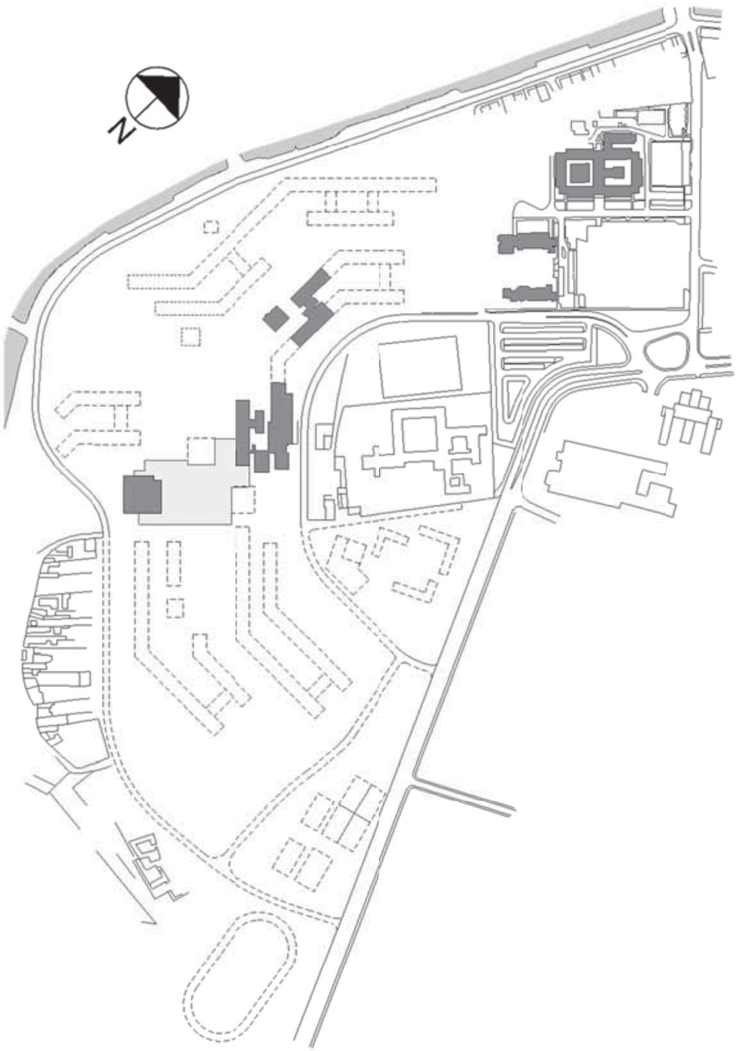


Figure 20.3
The Campus in 1987—dark grey: existing buildings; light grey: central square; dashed: first plan of the Campus.

A Heterogeneous Process of Urban Management

In 1998, another team of the Architecture Faculty of the University of Porto, also coordinated by Nuno Portas, after analyzing several urban plans, has presented its report about the Operational Plans of Intermediate Scale in Portugal. Proving the normative inflexibility and rigidity rules of the majority of these, the team recognized the importance of the resource, by the City Councils, to urban studies of informal character as a way to overcome this problem. The reading of the report emphasizes the recognition that informal plans allow urban questions to be solved in situations not predicted in the original plans. As they are elaborated with specific purposes, because they are performed according to concrete problems and with the object of the establishment of consensus between the parties, they have great flexibility.

Also, the team concluded that "the city is heterogeneous and diversified (…for that reason, the plans) that represent, guide and reconfigure inner development should be analogous to that reality. What is necessary is to define appropriate objectives to each situation, and, in accordance with it, choose the best way to fulfil them." The choice of different models necessarily implies the option for distinct forms of regulation of the constructions. It is what Nuno Portas designated in 2007 by "(…) variable regulation, that means there is always regulation, but this can vary gradually; in certain places should be stricter, in others could be wide open." The conclusions of this research represent the corollary of the practical experience of this team and reproduce the methodological convictions and the experience of urban management that the very own Nuno Portas has been categorically exposing in his writings and experiencing in the plans in which he has worked, of which the University of Aveiro is an example. Let us see: The urban management undertaken in the construction of the campus has consisted of a heterogeneous management process, often informal, illustrative of what the application of variable regulation is; He had the support, as we will see, of different instruments, chosen depending on the specificities of each situation and by harnessing the opportunities.

The Construction of the Campus of Santiago

In the initial phase, the CEFA's attention converged to the north zone of the campus. In the central zone of the northern departmental complex, whose construction had already started, the objective was to achieve, in a pragmatic way, an architecturally integrated solution:

a) The architectural project of the Department of Planning and Environment has been reworked with the objective of building an elevated circulation canal that would unite it to the (in the meantime planned) building of the Pollution Section.

b) The implantation and height of the building of the Pollution Section were informally defined, in dialogue with the architects, without the resource to formalized drawings.

The central zone of the complex was completed in an integrated way, with the same facade coatings of the remaining buildings involving the auditorium. At the north end of this complex, the goal was to finish the set:

c) To the Departments of Biology and Ceramics and Glass Engineering, the heights and the areas of implantation were established.

Simple rules were informally defined, in dialogue, seeking to create consensus with the architects that have had wide creative freedom. It consisted of creating, at ground floor level, a covered external circulation linking the two buildings and the adoption of identical frontages coverings (brick at sight, the material that became the assurance of the unitary image of the campus).

The Library Project, near the main square:

d) The elevated degree of conceptual freedom given to the architects by the urban managers was particularly notorious in the case of Siza's project for the Library, in which he was authorized to change the dimensions and the location of the building to open a lane from the campus to the Aveiro Bay.

In the peripheral areas of the campus, the problems were different:

e) The zone situated between the north departmental complex and the Aveiro Bay was an area for which the CEFA had not initially predicted constructions, attending to its environmental quality.

Figure 24.4
The heterogeneous urban management:
1. Complex of the Central Square; 2. Integrated Centre of Teachers' Training; 3. Department of Electronics and Telecommunications; 4. Isolated Auditorium; 5. Department of Planning and Environment; 6. First Students' Residence; 7. Pollution Section; 8. Department of Biology; 9. Department of Ceramics and Glass Engineering; 10. Library; 11. Buildings of the zone referred in e); 12. Students' Residencies; 13. Sports Zone; 14. ZDES (Zone of Departmental Expansion South).

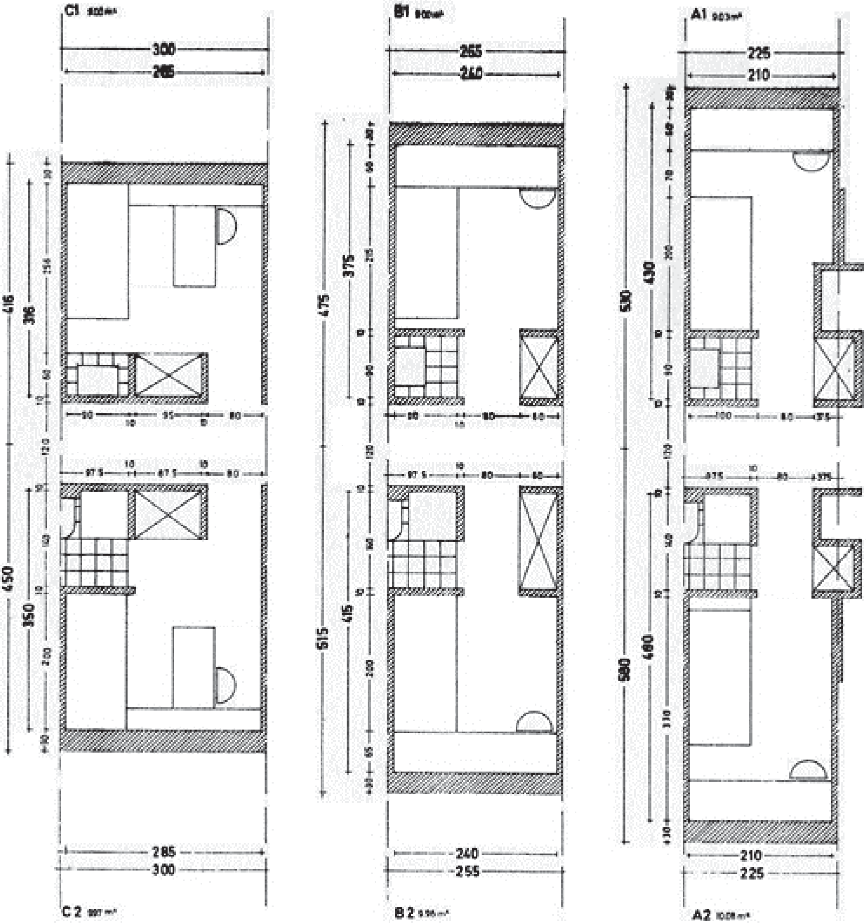


Figure 20.5
The “Residences Compared Topologic Study.” (Image courtesy of CEFA)

Figure 20.6
The Pollution Section the Department of Planning and Environment.

Figure 20.7
Department of Ceramics and Glass Engineering.

Figure 20.8
The Library.

Figure 20.9
The Students' Residencies.

There was, however, since the initial phase, the awareness that this *non aedificandi* status would be temporary. Confronted with the necessity of construction in this area (and only in that moment and not before), the process was managed, once more, informally. Nuno Portas made a simple sketch of the implantation of the buildings on paper, A4 size, following the principle of the least possible landscape obstruction. The same rules concerning height of the buildings and frontages materials used in the departmental north complex were also established.

f) The zone of the Residences has been kept in the same area as predicted in the original plan. By the time the revision of the plan was elaborated, there was only financing for the construction of 500 rooms. For that reason, the Students' Residencies were the only buildings defined rigorously in the new plan.

The process has passed by the execution of a "Compared Topologic Study," non-binding, which assured the viability of the proposal contained in the plan. The buildings were located in double side band, making an urban front to the street, relating more with the existing road structure than with the center of the campus.

g) The Sports Zone corresponds to another area where the maintenance of the originally intended function in the original plan was confirmed. The great dimension of the equipment, namely the Athletics Track and the Football Field, entailed the implementation of a "Detailed Study."

h) The Zone of Departmental Expansion South was designed in the new departments of teaching and investigation. In this area, a process that came to be known as "The Urban Project," in the actual definition that Nuno Portas gives to it, was rehearsed.

The Urban Project and the Zone of Departmental Expansion South (ZDES)

In ZDES, existed, as seined, certainty about the function of the buildings but great uncertainty either on the specific programs of the departments or on the construction times dependent on Community funding. In 1998, Nuno Potyas defended that, to deal with the problems related with uncertainty and time, the Urban Project must "store degrees of freedom between its parts without losing with it elements of continuity and readability."

The supports, ensuring the permanence of these elements, are the collective public spaces as the streets, squares, and gardens. "In other words, are the spaces that give continuity to the city, serving and connecting buildings" as they are collective, they live on. For this reason, he consecrated, in 1998, the notion of "ground project." "This type of intervention (has as bases) an independence (…) between the support it serves, and the edification that will be served and which prediction may inclusive be changed."

On the other hand, in 2005, Nuno Portas emphasized the importance of the demonstration made by Leslie Martin in "The Grid as a Generator" (1972): "as the city was organized and should continue to be organized spatially from the tracing of the support mesh." This observation legitimized him, in 2002, to question: "What kind of elements can give unity (…) to the city?" Then respond: "What is needed is to 'mesh out' (...the) city, is to introduce a mesh" that organizes those collective spaces.

The Process Followed in the Organization of ZDES Area

The process followed in the organization of ZDES area was sequential:

> Firstly, it began with the introduction of a mesh, established and partially modulated from the pre-existing alignments. The mesh base module has been set from the class spaces most commonly used at the University of Aveiro—one classroom for thirty-two students.
>
> Secondly, over that mesh, taking advantage of the displacement of the Library, the central lane and the gallery, open to the Aveiro Bay, were introduced.
>
> Thirdly, perpendicularly to the central lane, the external spaces needed for the outpouring and insolation of the buildings were deployed.
>
> Fourthly, the departments, or the "parcels" as Nuno Portas has called them, were placed in the remaining space.

> Finally, the possibility of construction or union of the buildings on a zone defined as "commonplace," situated along the major sections of the gallery, was introduced.

Because of this process, we can state that the "parcels" were defined from the remaining space of the overlap of the various collective urban entities—the central lane, the gallery, and the spaces of outpouring and insolation (these last ones as if they were streets). The "ground project" that assures the independence of future constructions was thus defined, in the 1998 expression of Nuno Portas. The definition of this support structure—the layout of the collective public spaces—has been allowing Nuno Portas, on a quote of Grande (2012), to defend the possibility of "drawing the cities without having to draw the buildings."

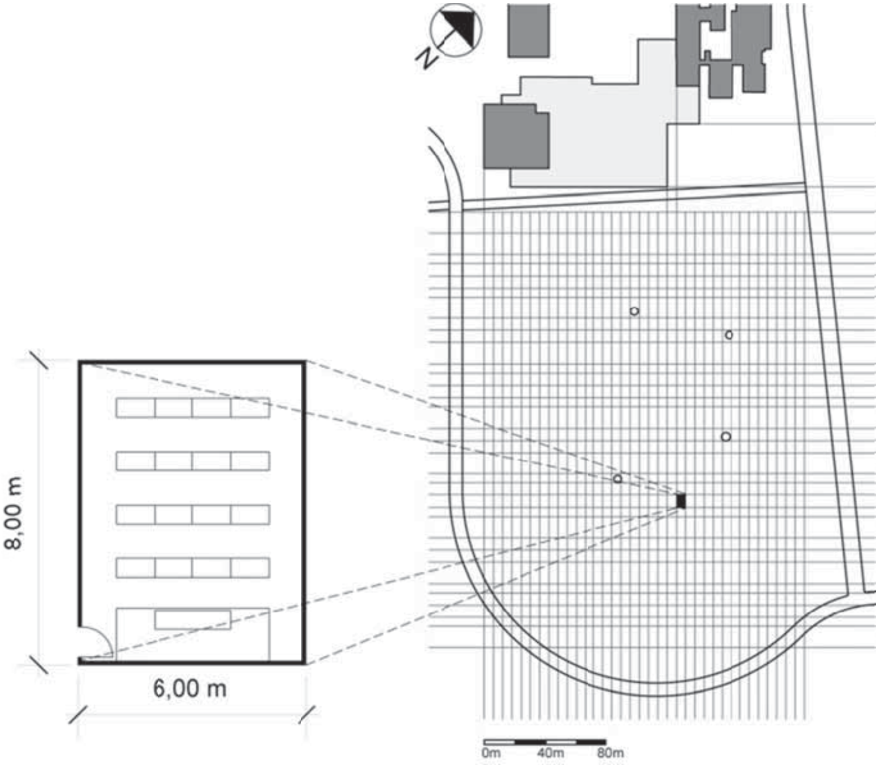


Figure 20.10
The organization of ZDES area with the introduction of the mesh based on the 32 students' classroom.

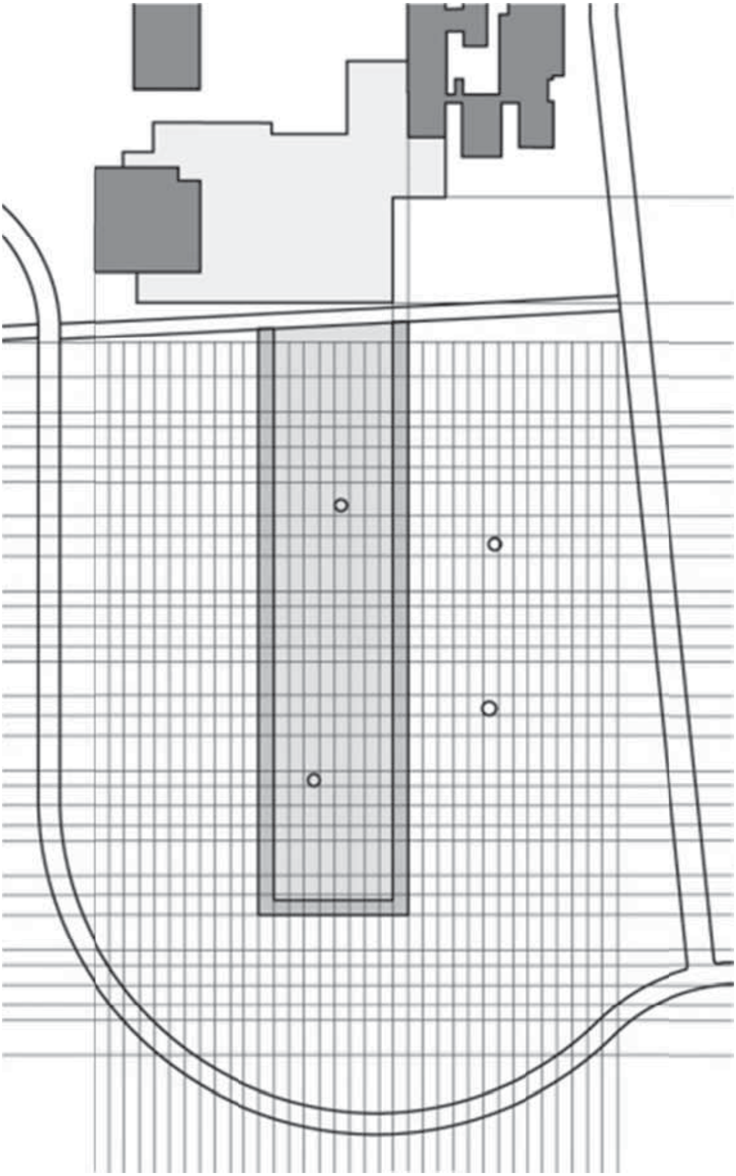


Figure 20.11
The introduction of the central lane and the gallery.

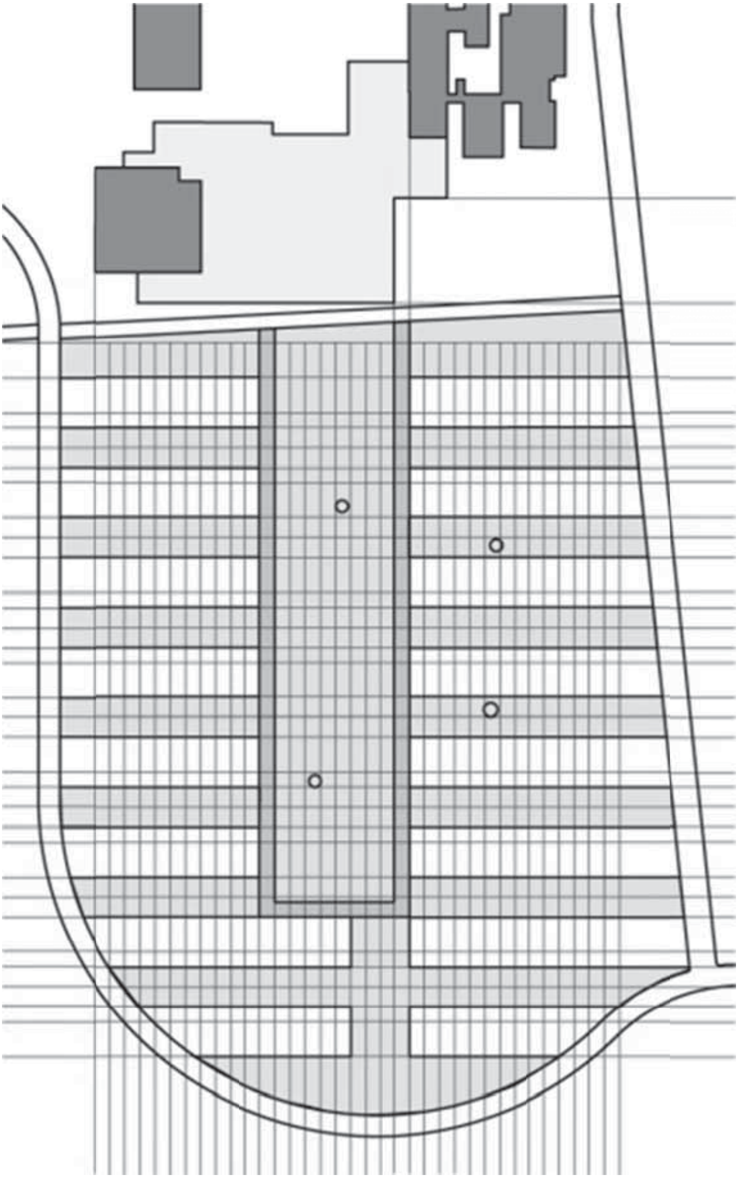


Figure 20.12
The introduction of the external spaces.

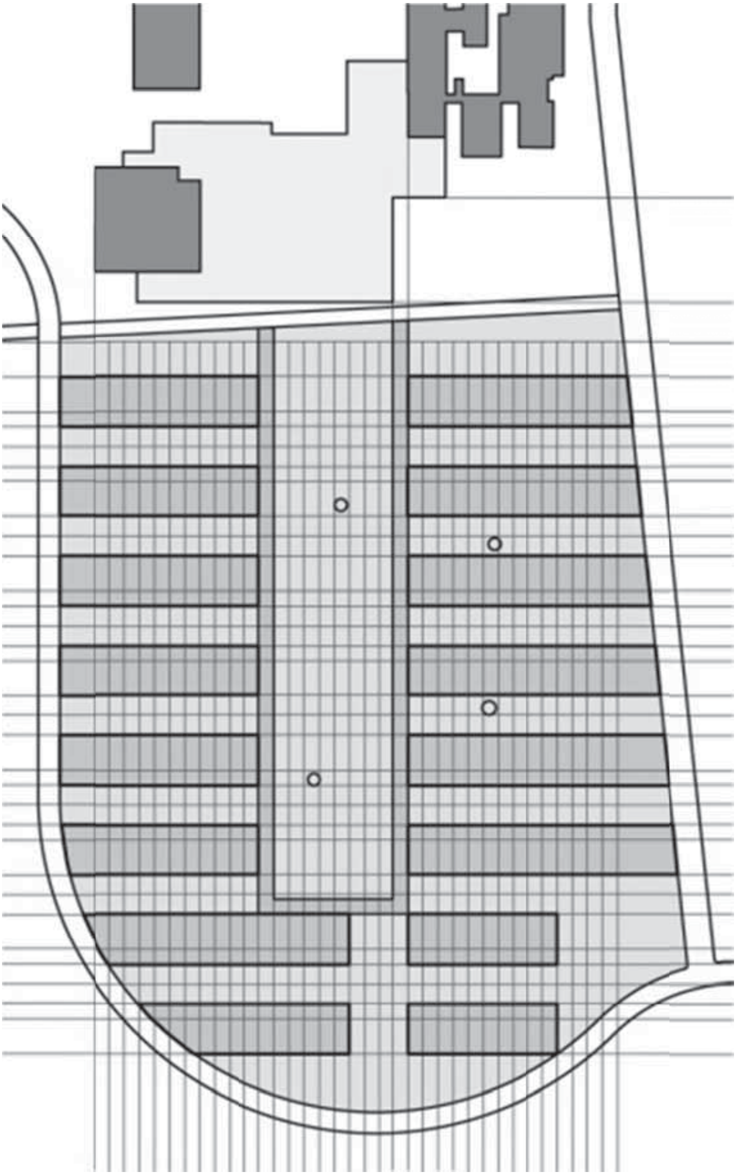


Figure 23.13
The departments (maximum area), placed in the remaining space.

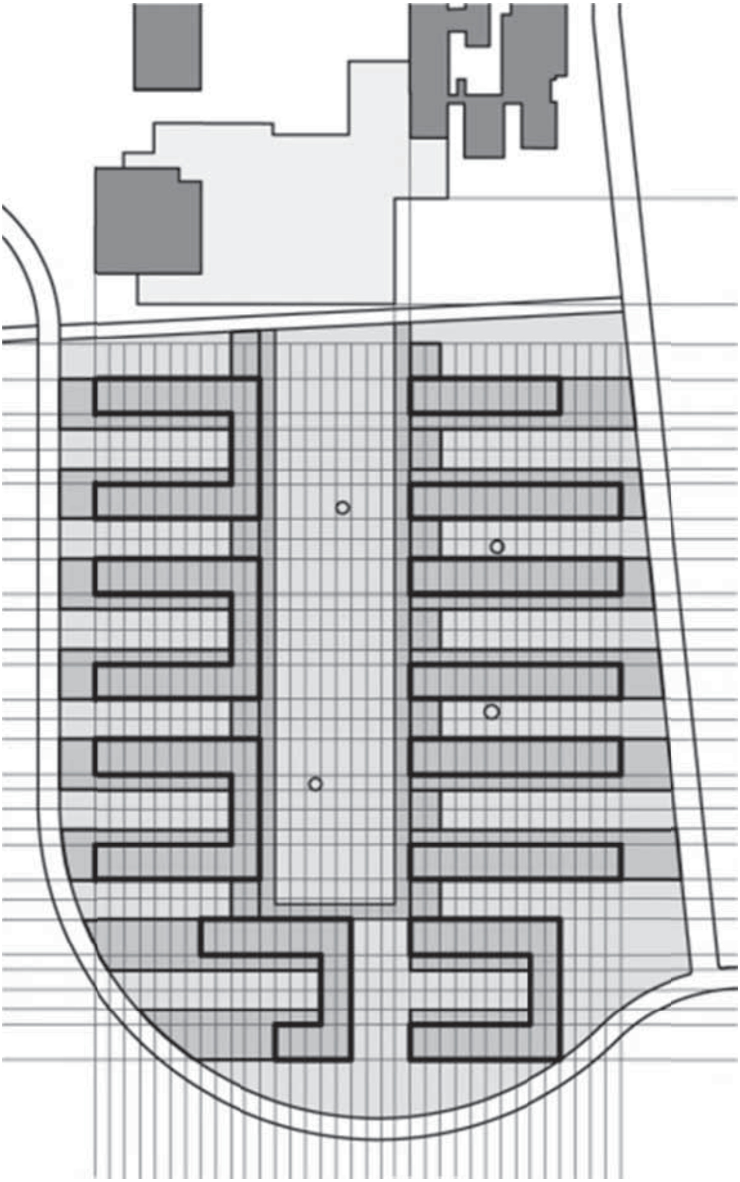


Figure 20.14
The introduction of the “commonplace” zone, the “U” shape and definition of departments’ minimum area.

The General Regulation of the Construction and the Terms of Reference

The "ground project," stated Nuno Portas in 1998, can "be elaborated as a project of execution for the public or collective space and as a set of rules." In the definition of the mentioned "set of rules," in other words the terms of reference that disciplined construction, continuing this, is placed the problem of how to replace "the determinism of the rules about what can be done (zoning of land use) by other kind of dispositions (...) on how to make it and with which criteria decisions must be taken (...)." The objective has passed, consequently, by the refusal of the imposition of the form of the buildings, to focus on ensuring what was considered most important, which was the framework of the buildings as a whole, ensuring the overall consistency of ZDES without unnecessarily conditioning the authors of the architectural projects.

Facts to Consider for the Conception of the ZDES Plan

It was agreed with the Rectory of the University of Aveiro that ZDES was destined to the construction of the buildings projected for the departments, but what the time phasing of the constructions would be was ignored. Knowing which departments worked on the university, there were doubts about the new areas of studies that might be implemented in the future (the opportunities), as well as the kind of spaces that these would need (the uncertainty). On the other hand, CEFA intended to make the use of the new facilities profitable, once the departmental and interdisciplinary character of the university led to a practice based on the mobility of the school community, being ordinary teachers and students attending classes in distinctive buildings of those where they were enrolled.

For a Flexible General Regulation of Buildings' Construction

It was therefore necessary to ensure flexibility in the general regulation of the construction of buildings. With this objective, some measures were adopted:

> Firstly, it was decided that the buildings would have three floors' height.
>
> Secondly, in order to enable the construction of buildings with different areas, were planned longer units on the eastern side and smaller on the western side.

Thirdly, in the shape of "U," assured the possibility of building departments of large dimension or yet the union of two of them.

Fourthly, the intercalation of constructions, in order to ensure the possibility of widening for the "parcel" adjacent of the facilities that were built on the initial phase, was predicted.

Fifthly, to ensure the flexibility in each "parcel," an area of desirable deployment (with 14m width) and a maximum area (with 20m width) was stipulated.

Lastly, a "commonplace" construction range situated along the gallery, of optional character and flexible dimension, destined as classrooms that could be attended by students from various departments was also defined. On the other hand, an "Occupation Regulation of the Departmental Units" complementary to the general rules was elaborated, which included three groups of "typological studies," of a character purely indicative.

1st Study: "Association of departmental spaces"—the simulation of the association of the spaces of the departments was studied in function of the two widths planned of 14 and 20m, and it aimed to demonstrate several possibilities of internal organization of the buildings.

2nd Study: "Association of the classrooms spaces"—to the commonplace track, eight kinds of classrooms with capacities that varied between thirty-two and one hundred and ninety-six students were studied. It was the dimension of the smallest classroom (the one of thirty-two students) that served of bases to the establishment of the module of the mesh that structures the ZDES.

3rd Study: "Indicative elements for the functional occupation of the departments"—this study aimed to present several hypotheses of desirable location of the functional cores of the departments, studied according to the optimization of displacement inside the building and the consequent decrease of the noise level.

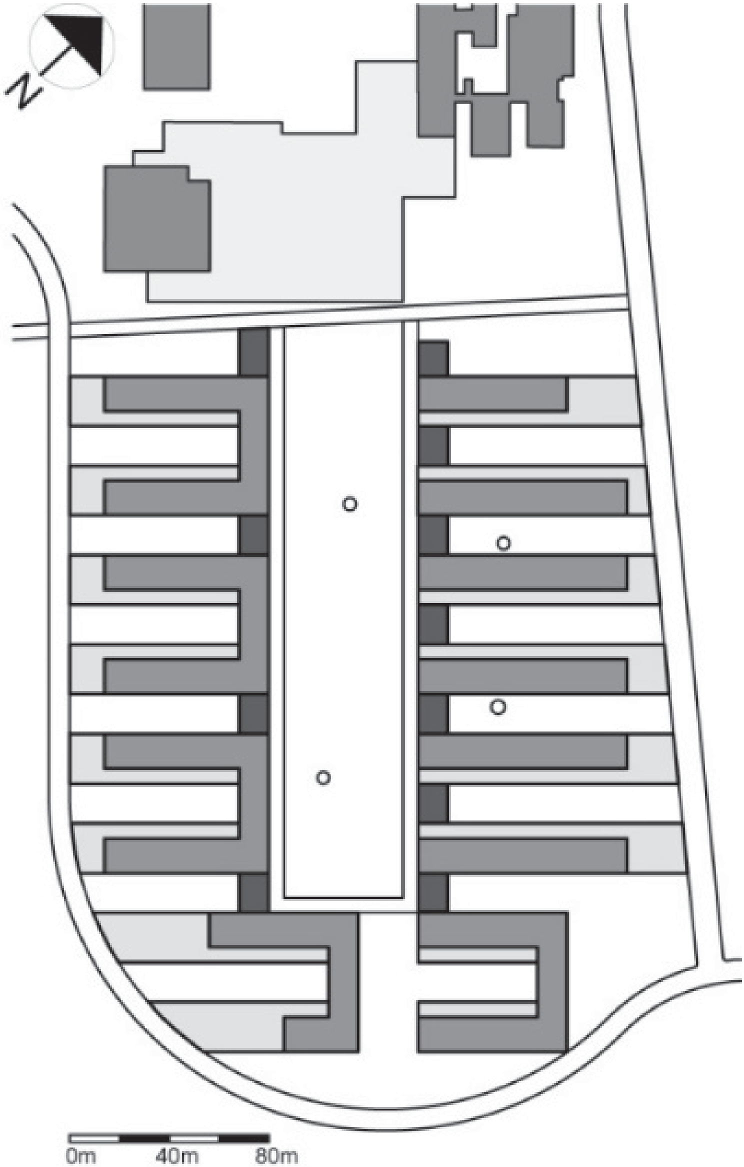


Figure 20.15
Grey: ZDES Departments desirable area; light grey: maximum area; dark grey: "commonplace" construction range.

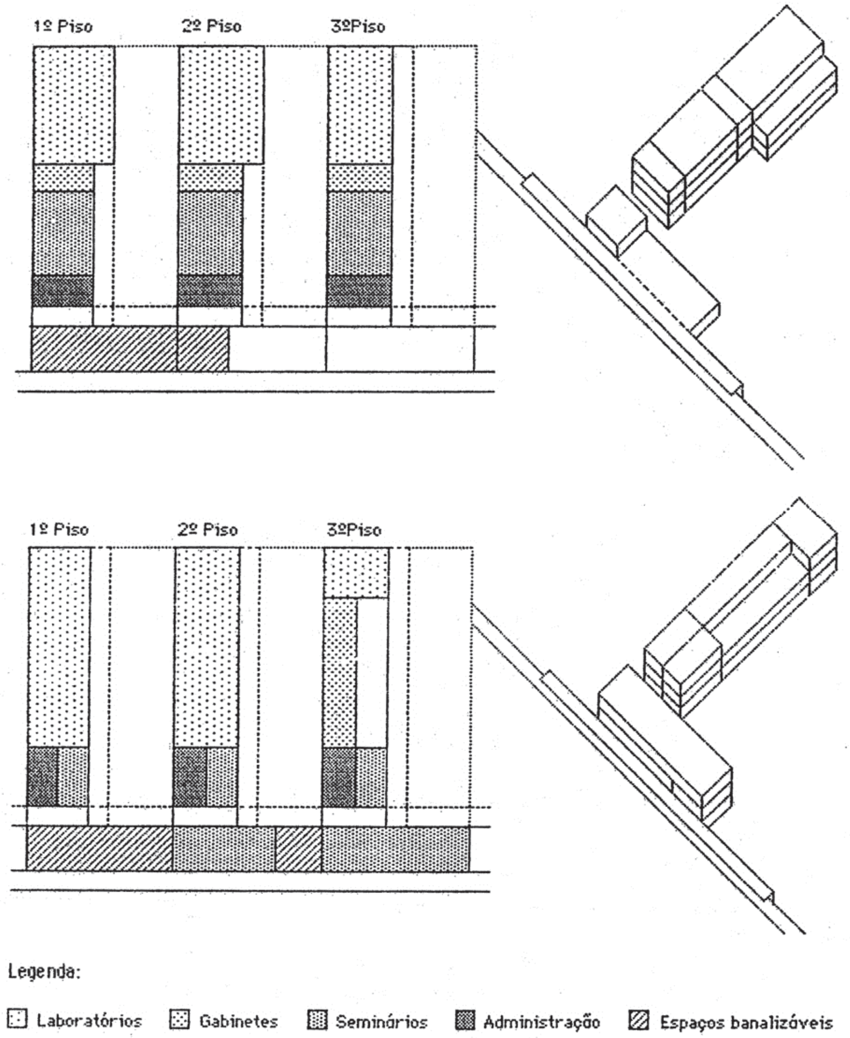


Figure 20.16
"Association of departmental spaces."
(Image courtesy of CEFA)

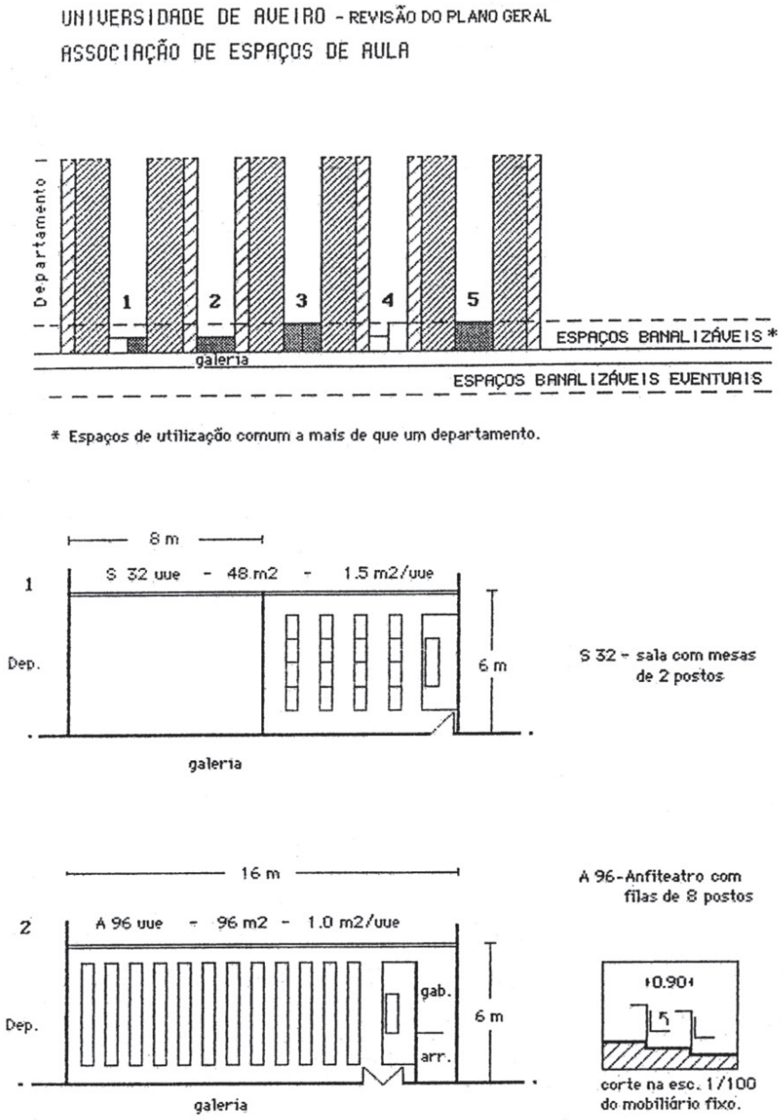


Figure 20.17
"Association of the classrooms spaces."
(Image courtesy of CEFA)

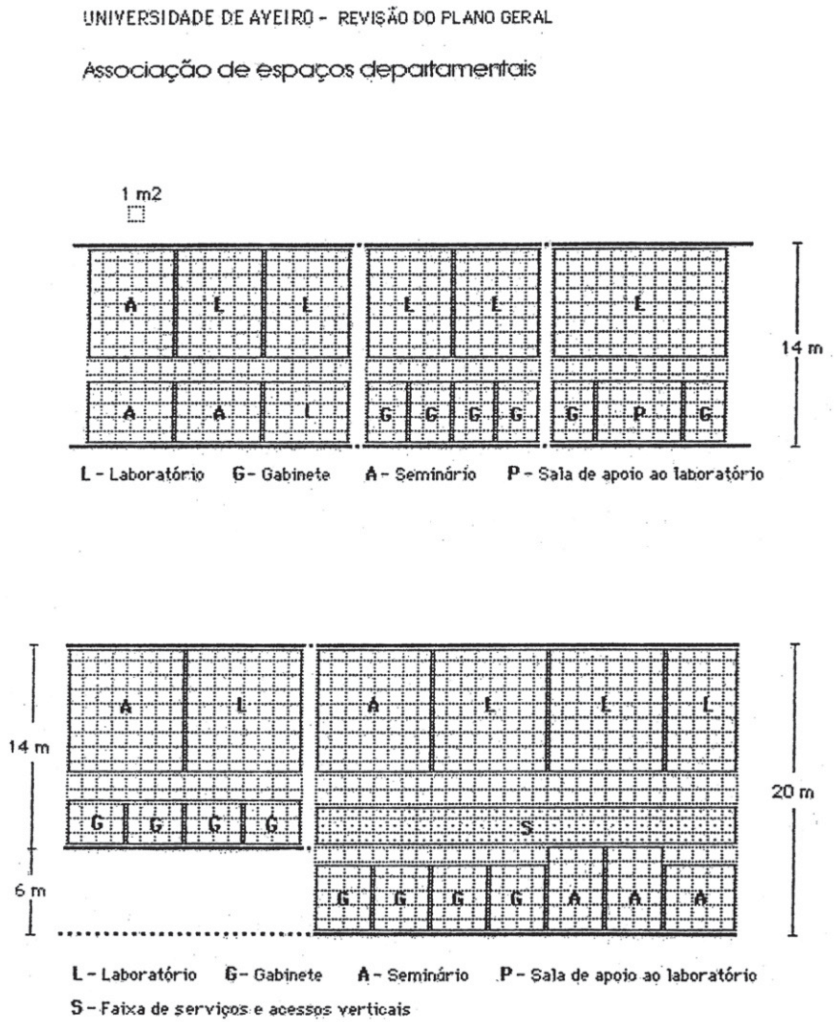


Figure 20.18
"Indicative elements for the functional occupation of the departments."
(Image courtesy of CEFA)

Briefly, it was recommended to locate the administrative spaces and the commonplaces close to the gallery, preferentially on the ground floor and the laboratory at the opposite end, close to the street. The seminar rooms and the teachers' offices, of a more restricted use of the departments, would occupy therefore tendentiously the core of the buildings or the upper floors, where fewer people would occur.

The Establishment of Guidelines and Rules with the Architects

In 1998, Nuno Portas, defended that, "to better resist to the unpredictable, the Urban Project must conserve liberty degrees between its parts without losing with it elements of continuity and readability." With the goal of establishing these elements, finished the Revision of the Plan, the CEFA met with the architects already contracted and, presenting the plan, in dialogue, sought the establishment of several consensuses about questions related with the construction of buildings. Of this meeting, has resulted the extension to all the campus of the regulation, never written, of the use of the brick in sight on the frontages.

The Matrix Idea: Towards a Unitary Conception

In 2004, on his "Last Class," Nuno Portas designated the RPGUA as an "Urban Project." In an "urban project, the priority is given to the assembling of the feasibility conditions, to the search of partners or necessary consensus, (...) being the location and the land in view only one of the data to have into account, and to compare in the time of decision, with other alternative possible although differing from those set." The method cannot be therefore the one of the traditional plan fixed in the design, and will now be a dynamic process that unfolds over time. In 1998, he referred that the method to employ will be then "interactive, introducing new information (from the part to the whole) during that term, testing the robustness of the assumptions (and admitting) its rearrange." So that an 'urban project' is open to opportunities, without the need for the revision of the plan, it needs the establishment of the support structure that ensures the immutability of the collective public spaces. This structure is defined by the "ground project." As we have already seen, this solution implies, as Nuno Portas affirmed in 1998, an "execution project for the public space and (...) a set of rules (...)." This was not the process followed in the University of Aveiro. What we can prove that was done in Aveiro was the use of an urban management process, diversified and heterogeneous, in which models were chosen over needs and the data available in each moment.

It is important to note that, even in ZDES, the most elaborated area of the plan, the collective zones were not defined rigorously; definition was only held later, and by others. Only with the Plan of Streets and Exterior Arrangements of the campus, was the form and the constructive solution of the collective areas of the campus rigorously defined. How was it possible, with a plan with these characteristics, to obtain the unitary result that the campus displays these days?

Discussion

What enabled this result was the capacity of Urban Management of the Plan that knew how to take advantage, based on the defense of the conductive idea, of the different processes used—true variable regulation—to guide, in each moment, the unitary construction of the campus. Comparative studies on the application of the regulations in the projects of the buildings of ZDES (conducted during the elaboration of the above-mentioned dissertation) have also shown that the managers uncompromisingly defended the plan whenever architects questioned its fundamental principles.

The Revision of the General Plan of the University of aveiro is not an "Urban Project" in the definition today defended by Nuno Portas, but it is perhaps "the" experience that allowed him to determine the underlying theory, as may be proved by the fact that the most part of the quotes here reproduced are from texts written long after the revision of the plan. The "Urban Project," in the current definition, is an open process of urban management, based in three essential points: the elaboration of the "ground project;" the definition of terms of reference; the use of a variable regulation. This methodological process, to deal with the variables, cannot dispense the implementation of a management based on the clear definition of the principle—the matrix idea—that generates the conducting wire that must guide all town planning operations.

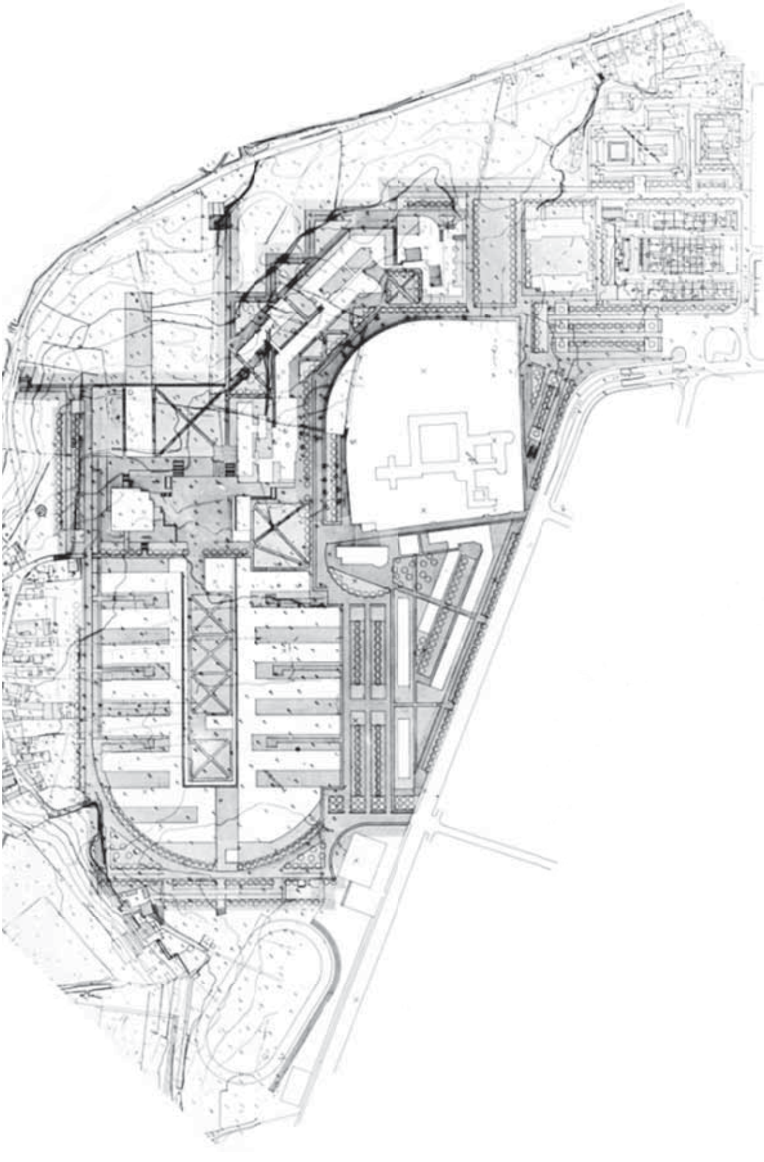


Figure 20.19
The Plan of Streets and Exterior Arrangements of the campus.[35]
(Image courtesy of Alcino Soutinho)

Figure 20.20
The Matrix Idea: towards a Unitary Conception—buildings in the campus.

Consequently,—and this aspect is particularly important—it cannot equally dispense of the uncompromising defense of that conducting wire. This is what happened in the Santiago Campus. Indeed, only the capacity, based on the strength of convictions, to follow the conducting wire outlined in the urban project can, with base in the use of the three essential points previously mentioned, lead to the possibility of the defense of its management.

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Translation

Liliana Azevedo

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– Part IV –

To Material Production

CHAPTER TWENTY ONE

NEW TERRITORIES OF CAM: MACHINECRAFT

CRISTINA NAN

Introduction

The variability of design and the design series is a topic often evoked. CAM and mass customization guarantee the unproblematic buildability of various design series. The variability of the machine according to a specific project would represent the next step. A move towards this direction was already taken by using robotic arms. A second approach consists in leaving the idea of the non-specific robotic arms aside and instead adapting customizable robots, as project specific tools, which are able to react specifically to multifarious constraints of a project. Thus, besides controlling design and informational processes, the architect would also be in charge of designing or reconfiguring machine devices and the corresponding robotic strategies. Apart from being the machine operator, he also becomes to a certain extent its inventor. By being involved in the development of robotic systems, a bidirectional process is set in motion: the adaptation of the machine to the design and vice versa. The architect becomes the organizer of conceptual robotic strategies covering the areas of design, material, structure, and machine development.

This theoretical framework will be substantiated by the robotics project "Minibuilders," developed at the IaaC-Institute. The project showcases the development of a robotic fabrication strategy and addresses the problem of transferring 3D-printing technologies to the construction site scale. Following a problem-solving approach, a plural robotic system consisting of three mobile, independent robots was developed. These are specialized according to their tasks, thus responsible for different printing phases. Coding and ultimately mathematics acted as main facilitators and led to a successful on-site printed protostructure.

Theoretical Framework

The last twenty five years of architectural development have been significantly influenced by the profound digitalization of the discipline. At the beginning of the digital turn, the main fascination with the new digital tools was primarily focusing on digitally influencing and controlling form generation. Digital fabrication tools were not completely excluded from the agenda of interest, but only after the first wave of form generation exuberance faded away did architects turn their focused attention also towards the means of digital fabrication and production. During this time span, the interest moved from multi-axial milling machines to laser cutters then to 3D-printers and reaching finally the robotic arms. A look at academic research pavilions suffices to read this development. The academic student pavilions mirror best the implementation order of the digital fabrication tools and act as an indicator for the shift of the technological attention allocated by professionals.

The implementation of the digital tools in the two areas of form generation and the making of form led to vast polemical discussions over the impact and the relevance the new processes will have over time. During these debates, a multitude of paradigm shifts have been evoked, the shift from mass production to mass customization, the shift from the analog to the digital just to mention a few. But leaving aesthetic and form orientated debates aside and concentrating on the constructive substance of architecture, the most relevant shift was probably "the paradigm shift in the production conditions of architecture" caused by the new generation of digital fabrication tools.[1] Founding the first worldwide architectural fabrication laboratory to include robots, Gramazio and Kohler argue that the division between the design process, understood as an intellectual act, and the fabrication process will be easily overcome through the use of robots by architects, as robots directly involve the architect to all processes.[2] It is important to not only concentrate on the use of these technologies and their implementation in the fabrication of architectural elements, but also to observe the changes which deviate, on an operational and structural level, from the use of robotic machines as direct tools of the architect.

One of the biggest advantages of the insertion of the robot in the architectural practice is the omission of an intermediary agent between architect and the fabrication tool. The architect himself is in control of the robot, by defining a set of instructions. By observing the way of evolution of

today's robots and their integration in the design, material, and constructive processes, the concept of architecture machines seems to be reactivated.[3]
The variability and variation of the design and thus of the design series is a topic which has been often evoked in architecture.4 Digital fabrication tools and mass customization guarantee the unproblematic buildability of various design series. The variability of the machine according to a specific project would represent the next step. A move towards this direction was already taken by using robotic arms. A second approach consists in leaving the idea of the non-specific robotic arm aside and instead developing for every project customizable robots or machines, as project specific tools, which are able to react specifically to the multifarious constraints of the project. This is where the self-developed term machinecraft ties in.

Machinecraft describes the ability of the architect to be involved in machine development, adapting and customizing machines according to design and material requirements. Thus, besides controlling the design, material, and informational processes, the architect would be also in charge of designing machine devices and the corresponding robotic strategies. Apart from being the operator of the machine, he would also be to a certain extent its inventor. By involving the architect in the development of machine systems, he sets a bidirectional process in motion: the adaptation of the design to the machine, and of the machine to the design. The multidisciplinarity of the discipline would be once again extended in the spirit of the masterbuilder's paradigm by the example of Brunelleschi.5 The architect would be the organizer of a conceptual strategy that covers the areas of design, material, structure, and machine development. The forgotten relationship between the architect and the machine as an invented tool of fabrication would be revitalized. Like this, the link between the design, the image of what is to be constructed, and the making of the materialization of this image is being reinforced.

Current State of Research

From the multitude of academic and non-academic robotic projects, three research endeavors conducted by Neri Oxman, Enrico Dini, and Behrokh Khoshnevis, can be considered to play an exemplary role in the advancement of the field of self-developed robotic and machine strategies with regard to the implementation of 3D-printing technology and to be important for the contextualization of the further presented case study. Oxman engages in a holistic approach, developing a strategy that covers and intrinsically unites the processes of design and fabrication: variable property modeling (VPM) and variable property rapid prototyping (VPRP).

Following the example of highly optimized natural material distribution, Oxman explains her methodology as an interlinked process chain of modeling, analysis, and fabrication which results in objects that "correspond to multiple and continuously varied functional constraints."[6] At the current state, VPRP is a technology that is not yet applicable for the construction site. One reason lies in the use of resins as construction material, while the second is connected to the size of the used machine, its reduced size depicting a considerable limitation to itself.

Developed by the inventor Enrico Dini, D-Shape represents a fabrication process that is very similar to general 3D-printing technologies following a horizontal layer-by-layer material depositing strategy. For this technology, a custom-made material was developed, consisting of sand and a mineral binder, the result being similar to artificial sandstone.[7] Other than the resin and plastic composites used at other 3D-printing technologies, the custom-made material of D-Shape seems to implicate considerable benefits in terms of its sustainability, and material resistance. Contrary to VPRP, D-Shape proposes for now an undifferentiated material depositing system and can be considered a scaled-up version of an industrial 3D-printer.

Behrokh Khoshnevis, professor at the University of Southern California, developed the technology of contour crafting (CC), defined as a method of layered manufacturing that may employ a diverse range of printing materials used for the realization of architectural structures.[8] The technology distinguishes itself by taking various aspects of the construction site into account, which are neglected by most comparable projects. Besides offering a wide material range, from smart concrete to ceramics, it offers automated solutions for the integration of reinforcement elements, plumbing, electrical wiring, and even tiling.[9] Thus, CC enlarges considerably the technological complexity of 3D-printing in accordance to the intricate demands of architecture.

The Case Study

The previously described theoretical approaches and constructs will be exemplified and demonstrated on an applied case study. The case study at issue, bearing the name Minibuilders, was developed as a robotic research project at the IaaC Institute in Barcelona.

Project Agenda

The main aim of the project consists of the development of a robotic fabrication strategy that is suitable for the on-site construction use and offers additional substantial benefits to existing technologies. Prior to starting to develop a precisely detailed project agenda, the first step of the research consisted of collecting data about the current utilization of robotics and the appendant employed materials. A multitude of diverse robotic technologies, most of which originated from car design, ship building, and aircraft industry, were investigated. Close attention was given to the academic field, as it offers a higher variety of experimental robotic applications. Another center of interest concentrated on 3D-printing technology and its architectural applications. As a second step, the collected data of multiple case studies was analyzed and evaluated, in due consideration of predefined comparative criteria. Subsequently, the four following limitations of robotic arms were identified as main impediments to achieving a more complete implementation of robotics into the applied field of architecture:

- Limited reaching area.
- Limited mobility. To extend the reaching distance, robotic arms need to be moved on tracks or placed on moving platforms, which implies the input of additional effort and the creation of an infrastructure.
- Weight and size. The average weight of an industrial robot arm amounts to approx. 600kg. This weight can represent an impediment in terms of fast and flexible motion, while on the construction site it depicts additional load, which needs to be considered. The size of industrial robots corresponds to their weight, so that they can be considered as large-scale fabrication tools. A restricted accessibility can be derived out of this.
- Restrained range of application. Excepting very few examples, such as the ICD/ITKE fiber-woven pavilion 2013/14, where the robot engages in a continuous construction workflow that results in a finished pavilion, robot arms are normally used to perform only parts of the fabrication, construction, or assembly processes. Therefore, if we look at the entirety of building processes, they rather represent auxiliary, supporting tools assigned with secondary activities.

The identified and enumerated disadvantages represent features, which can be interpreted as such from the builder's standpoint, having in mind the construction site. In the context of their area of use, such as performing at an assembly line, these features represent high-value assets. Resulting from the before detailed analysis and the elaborated determining factors, the research group concluded on the following three objectives, as detailed below, to be covered by the developed project:

- The main set goal is defined as developing a robotic strategy that covers the construction process as a whole and is designed for on-site use.
- The second requirement aims at technical specifications regarding the aspect of scale. Other than industrial robot arms or building site equipment, the developed machines should exhibit the following features: lightweight, small size, and autonomous mobility. Satisfying these demands leads to flexible, easy maneuverable machines. Yet, the reduced size and weight should impose no limitation to still being able to construct normal scaled structures.
- Sustainability in relation to material usage represents the third set goal. Taking into account the general bias towards the non-standard curvilinear designs, the decision was taken to focus on offering a solution for fabrication challenges that derive from such geometries. Building curvilinear shapes often implies the use of an on-site scaffolding, an elaborate production of casting molds, or high figures of material offcuts. Thus, material usage, energy footprints, and labor time can be reduced just by developing a technology that is not reliant on the use of scaffolding or molds.

Robotic Construction Strategy

Preliminarily, it is important to state that all focus and effort have been invested in the developing of an operational construction methodology. Therefore, this chapter is concentrating on the attempt to highlight the relevance of self-developed robots and the importance of the interrelation between design-material-machine. Due to this approach, profound technical details concerning aspects of mechanical engineering or programming will not be described extensively. Following the same reasoning, the design depicted in the following pictures is irrelevant in terms of its formal aesthetics and was deliberately kept minimal. To meet the previously mentioned requirements, a robotic strategy for on-site fabrication was developed.

The strategy is predicated on the development of a series of mobile robots, which can act independently from one another and thus fulfill separate functional demands. The three developed machines (Figure 21.1) with their built-in technology represent a hybrid between robotics and 3D-printing: while the mechanic specifications correspond to the ones of robots, the integrated material deposition system correlates in its procedural features to the functioning of 3D-printers. The drafted strategy relies on dividing the on-site construction processes into three phases, according to functional necessities. The three phases are consecutive and each correlates with the use of a different robot. The first robot, the foundation robot, to come into operation is responsible for raising up the first ten to fifteen layers, which form the foundation of the future structure (Figure 21.2). Subsequently, after the foundation is finished, the second robot continues depositing the following layers and finalizes the design. Whereas the foundation robot is capable of moving on the ground, the second robot, named grip robot, needs to be manually positioned on top of the finished foundation layers. According to the task it needs to fulfill, the grip robot is designed as a type of climber robot. After being placed in its position, the grip robot continues with the successive deposition of the layers. As the deployed material is a fast hardening two-component resin system. The grip robot features two heating devices, which, if activated, reduce the curing time and the extruded layers can accurately set on time, thus ensuring structural stability and support for the grip robot to continue its movement. The grip robot completes the form and is responsible for the main construction task.

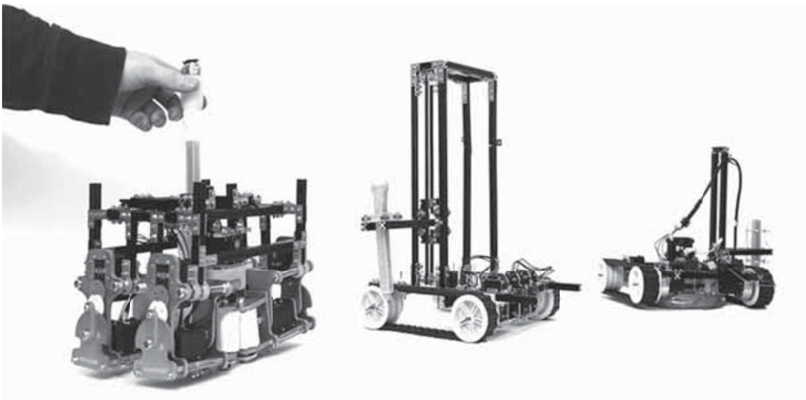

Figure 21.1
Minibuilders – from left to right: grip robot, foundation robot, vacuum robot.

Figure 21.2
Minibuilders connected to industrial extruder on the construction site.

As both the foundation and the grip robot deposit horizontal layers, any resulting structure, independent of its shape, will exhibit a restricted structural stability. Naturally, the cause of this lies in the absence of vertical reinforcement. To counteract this effect and to offer an increased structural stability, vertical layers along the horizontal ones must be added. Concluding, the third phase seeks to address this problem and deals with the construction of the earlier mentioned reinforcement layers. This stage is based on the utilization of the vacuum robot. Whereas the foundation and grip robots follow a horizontal line of movement, the vacuum robot is designed for ensuring a vertical motion. As indicated by its name, the robot creates a vacuum between himself and the surface of the structure to be able to advance vertically. Similar to its predecessor, this robot also needs to be manually placed on the structure. It then moves along the structure, by following predefined paths. These pathways originate from a previous, detailed structural analysis of the design. They derive from force flow lines and represent abstractions of these lines, which were simplified for printing purposes. After the completion of this last layer, both design and construction process can be considered as finalized.

Material supply and depositing strategy

All three robots are connected to an external, industrial extruder, which contains two buckets filled with a custom-made, two-component resin system. The custom material was developed simultaneously and in accordance with the robots. In this case, robots and material are intrinsically connected to one another. Information on the material behavior, which was gained from conducting a series of material experiments, operated as determining factor concerning the mechanical development of the robots. Material viscosity, mixing ratio, and curing times would influence the extrusion rates and speed up to the physical elaboration of the robots.

During the extrusion, the two-component system is being mixed together and then deposited as consecutive layers by the robots. Being a resin based system, after the mixing, the chemical reactions induce the material curing. Depending on the layer thickness, outside weather conditions, temperature and humidity, and the adding of an external heat source, the curing time can vary or be deliberately influenced.

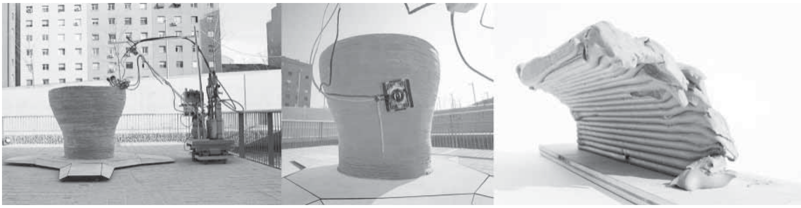

Figure 21.3
From left to right: grip robot finishing structure, vacuum robot moving vertically and depositing reinforcement layers, printed curved wall element.

Curved surfaces can be easily achieved without the use of a supporting structure. This was solved by exploiting the material behavior of the developed resin system. The adhesion between the consecutive layers is so high that even curved elements with an overhang can be printed (Figure 21.3).

The applied robotic printing strategy and the operating mode of conventional 3D-printing devices are similar in nature, but differ in so far as the way of the material depositing is concerned. A diverse range of different 3D-printing processes exists, starting from fused deposition modeling to selective laser sintering. All these processes are based on printing consecutive parallel cross-sections of the model.

The grip robot discussed here follows a slightly different material depositing strategy. It deposits the layers as a continuous spiral and not as a sequence of parallel cross-section layers. This means that the finished design model is processed by a custom-made script, which redefines the shape that is to be constructed as a continuous spiral.

Future Fields

A first step in the broader development of the showcased project would lie in the refinement of functional subdivisions according to the necessitated architectural elements. For now, the foundation, walls, and structural reinforcement were addressed. Extending the list, for instance by differentiating between exterior and interior elements, would lead to an increased number of specialized robots. Another desirable and beneficial enhancement of the technology could lie in extending this additive manufacturing procedure by equipping the robots with the capability of simultaneously adding and subtracting material, so that small construction or material deposition errors can be rectified in real time.

Discussion

The described project, with its underlying construction strategy, depicts schematically both a work approach and a procedural method, which are in an early beginning stage. Nevertheless, it illustrates the benefits of the involvement of the architect in the assembly of a comprehensive strategy, which covers aspects of design, fabrication, and machine construction. By engaging the architect into robotic development, he can implement and adjust fabrication or construction strategies that are fully adapted to architectural specific needs.

Being involved in the mechanical development of the construction tools asks for a complete understanding and participation of the architect in the material research. By a detailed understanding of the material and through the collaboration with material scientists, it should be possible to generate modified materials according to the specific needs and demands of both the design and the machine, so that they best fulfill the requirements of the developed construction strategy.

The machine turns into a design agent of equal importance with other parameters that influence the design and its materialized quality. Through the integration of self-developed machines or robotic devices as autonomous design agents in the architectural process, a complete liberalization and democratization of the discipline could be achieved.[10] The high level of skepticism regarding the dematerialization of architecture through the extensive use of digital fabrication tools proves itself to be superfluous.

Gramazio and Kohler argue in benefit of the deep impact robotic arms had, claiming "that the robot engenders a fundamental alteration in the discipline's constructive understanding of itself."[11] The robot is seen as a catalyst between architecture and construction, which strengthens further this relationship. If the potential of the digital is understood correctly and applied in a suitable way, the digital can lead to the reinforcement of the material and constructive nature of architecture. Through the use of robots or robotic machines, a convergence of architecture and a new type of handcraft is being facilitated. The following quote by Kieran and Timberlake summarizes most adequately the potential that can derive from the simultaneous reengagement of the architect with different fields of specialization: "While we cannot return to the idea of the masterbuilder embodied in a single person, the architect can force the integration of several spun-off disciplines or architecture—construction, product engineering and material science—all with the aim of reuniting substance with intent."[12]

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CHAPTER TWENTY TWO

INNOVATION AND TRADITION: CRAFTS IN DIGITAL AGE

PEDRO CAMPOS COSTA
AND KATARZYNA AUGUSTYNIAK

Introduction

The ideas described in this chapter arose from the experience of Campos Costa Arquitetos' practice in investigation and experimentation on raw materials such as cardboard and cork, and use of various manufacturing methods for their treatment. Several years of development of the concept under CACO brand made us seek unconventional methods of design and production of the objects in the mentioned materials. Under these circumstances, we reached the point where we reconsidered the typical dichotomy between what is technological advancement and what is traditional, we observed the process of creation in which the traditional craft and advanced technology melted together into one coherent workflow.

Significant for each period of technological progress, also nowadays, we are witnessing the slight "anti-technologism."[1] As in the early 20th century, the fear came out of the risk of losing a job for masses of skillful laborers caused by the mechanization of the production process,[2] recently the more common reason seems to be the longing for a lost authenticity. The mass production and automatization made us look back at the traditional carpenter´s workshop and praise the beauty of the true work of hands. We observe the idyllic longing for the traditional craft.[3] It is enough to put the artisanal adjective to any kind of project to make its sales increase.[4] Among architects, it is not rare to meet the opinion that digital design tools caused dehumanization of the profession, where the authorship and creativity gives way to repetitive, bizarre digitally-generated forms.[5]

This chapter aims to prove that authenticity doesn't necessarily need to exclude the technology and innovation. We want to argue that advanced fabricating techniques can give a new life to what we call craftsmanship, rather than substitute it. We believe that, wisely used, they lead to reintegration between architecture, art, and industry. They can bring architects back to the construction site and enhance them to the development of individual solutions rooted in their place and time.

What is Craft—Definition and Characteristics?

Basing our discourse as the opposition to common presumption that technology is contradictory towards a craftsman,[6] we must first take a look at the meaning of those terms. As much as technology has well defined significance, the other term tends to be problematic.[7] Although the common definition of craft includes the aspect of making something with the use of hands, the Oxford Dictionary describes also the other meaning: *"Skills involved in carrying out one's work."* Skills and quality are the strong characteristics that occur always where one speaks about the craft. In the prologue to his well-recognized book, Richard Sennet refers to craftsmanship as "the desire to do a job well for its own sake."[8] This struggle for the quality is inseparably connected with this term.

On the other hand, one could argue that the invention of mass production had the same intention—to provide the high-quality products and more, make them accessible for masses. Founders of Bauhaus have seen standardization as a way to bring the finest solutions into common use. What is, therefore, a thing that distinguishes the craft from mass production apart from, as is commonly believed, the use of "hands"?

In 1968, David Pye was trying to describe the difference most explicitly pointing out the factor of risk that increases while we move from technological processes towards craft. He emphasizes that it is not necessarily the issue of the type of the tool that is used (one should not forget that most of what is traditionally described as handmade is created with the help of more or less sophisticated tools) but the certain dynamic of the process of creation, which includes experimentation and errors that distinguish one from another.[9] The most recent publication of Mario Corpo presents the view that stays in line with Pye´s belief, saying: "craft means unpredictability, variability, improvisation and decisions that are made on the fly."[10]

That leads us to another characteristic of craft, which is a uniqueness of the output of the work of man. The presence of man in the creation process, a possibility of immediate reaction to unpredictable difficulties is what makes crafted objects so special. We tend to see authenticity in the imperfection, signs of the human touch in so-called handmade objects. The romantic picture of the working man comes from the writing of Diderot and Ruskin. Two of them, although fascinated by the workmanship, did not really practice it in their own lives.[11] Though in a way bucolic, Diderot´s vision of craft praised "heroic struggle" for the sake of quality work; Ruskin, on the other hand, glorified the vitality of the working class in the opposition to spoiled elites.[12]

In the beginning of the 20th century, yet another look on the idea of craftsmanship appears. *Deutscher Werkbund* aims for a reunion of art, industry, and handicraft and creation of new forms through the stimulating mixture of those areas.[13] In the eyes of Gropius Bauhaus, was a place to create a "new guild of craftsmen" with the emphasis of the practical way of obtaining the knowledge. Although referring strongly to the term of craft, he was never refusing technology—in the same manifesto he calls for "humanistic technological culture."[14]

Digital Craft—Oxymoron or Not?

Mario Corpo, in the interview by Matthias Kohler, describes both traditional craft and advanced digital methods as processes *"where the result is born out of dialog-based relation between the craftsman and the object he is making or the material."*[15] Can we therefore speak about a digital craft?

If we take the above-mentioned principles of craftsmanship, we will find many of them mirrored in the digital manufacturing methods: the direct interaction, the need of mastering the tool, the objective of the finest quality, finally the authenticity—uniqueness of the objects. The digital fabrication methods enable one to bypass a traditional blueprint as a principle means of architecture and act immediately on the material itself—switch from the static process to the dynamic one, where the designer has a direct influence on the making.[16] Kohler (2014) argues that the former physical presence of the architect on the building site can be substituted by the virtual presence, which allows responses to unforeseen conditions, basing his experience on the Gantenbein Vineyard Facade in Fläsch from 2006. Following that thought, we could consider it as a reflection of the ancient presence of the building master on the site, when the difference between architect and craftsman didn't exist yet.

As our experience shows, that, as much as physical model-making, operating the CAM cutter requires a great deal of skills, especially when it comes to work on an unusual material such as cardboard. Appropriate setting of the machine, depending on the material behavior and complexity of the action to be performed, is also a sensual skill that can be gained only through experience and experiment. Sarah Kettley (2009) argues that this specific engagement between material and a maker is what distinguishes craft and makes it authentic.

Authenticity takes us back to the issue brought up previously. Recently, we are witnessing a turn towards handmade objects (traditional craft). It is the concept of craft being authentic and unique that makes it such a "compelling promotional tool."[17] In fact, what we are searching for is the finest quality of the product that was made for us with special care, maybe even customized to fulfill our special needs—we want something personal.

Usage of digital design and manufacturing methods allows customization in a scale that was difficult to achieve in the former times. Moreover, it enables the reintegration of the entire process from the design to construction that, depending on the scale, can be performed by a single person or little team. The CAD-CAM techniques allow the fast prototyping without the necessity of remodeling an entire production line. They enable a jump from the scale modeling directly to the 1:1 mock ups.[18] Consequently, stimulating the experimentation and creating a link between industry and designers.

Case Study

CACO and Other Experiences of CAMPOS COSTA ARQUITECTOS

In our practice, we have been developing, since 2010, the (R)innovative tradition concept, which is based on the combination of digital fabrication methods with raw materials like cardboard and cork. Working with several technologies of cardboard and cork processing, CACO aims for the implementation of new contemporary models into the traditional sector.

Using those "poor" materials, one of which is inseparably connected with the Portuguese tradition, we are aiming to find unconventional applications of them. Our approach stays in line with Pye´s (1968) conviction that good material is a myth and it is its preparation, treatment, and formation that implements the finest quality.

The starting point of the investigation was the commission for the rehabilitation of the interior of LOW bar in Bairro alto in Lisbon, where we proposed an organic form build entirely with cardboard. A large cardboard wall-piece assembled without any gluing along a wall. It assumes multiple functions, from a bench for customers to a bookcase that supports the service of the bar. The organic shape is related to its functionality. The metamorphoses that take place along its length are made according to the required height as well as the rhythm and spacing of the cardboard plates.

At that time, we had been using Autocad 3d modeling for form-finding, the cardboard pieces were then cut using CNC technique and assembled by hand. Based on the sustainable concept of reduce, reuse, recycle, we mixed the recycled material and digital technology for its treatment to provide a dedicated object that is both ideologically and formally suitable for its place. The successful delivery of the Low bar project was followed by several experiences with the use of similar techniques and the same material.

An interesting case was the design of Rolling sofa—where the original design resulted in two divergent objects. A piece of furniture was originally proposed in cardboard layers, that later needed to be reinforced with MDF toppings. The initial form studies were performed in Rhino with the objective of creation of the sofa with the variety of seats along it (subsequently cut in the three modules, one of which was chosen and repeated).

After we had finalized manufacturing of the rolling sofa, which combined digital cutting and handmade assembling, we experimented with the same initial form in the other material. In order to do so, we cooperated with the company that specialized in production and formation of cork. The specific characteristic of the material forced us to modify the design and reduce the overall size of the object. Constraints of the materiality resulted in an object of a different character. This example illustrates the crucial characteristics of craft, which is the dynamic process—described by Kolarevic (2008) and Pye (1968) as a “workmanship of risk,” where the final effect is not preconceived. The objects evolved in the process of design (that's well known among architects) but also within the fabrication trial.

Campos Costa Arquitectos delivered, in 2015, a project of extension and rehabilitation of the Ozadi Hotel in Tavira. Within that project, we developed a few objects in cork under CACO brand that were dedicated to the hotel interior. The concept of the hotel project is based on the balance between locality, tradition, and modernity.

The fundamental aspect of the new structure is the concern for comfort, as much as a balanced and harmonious relation with landscape, while asserting its personality and character. Those qualities are manifested among others in the use of cork for the bedside tables and lamps—the new form given to the typical Portuguese material in its purest nature.

Pieces designed for Ozadi followed a similar process of design and fabrication as the previous products of CACO. In fact, the bedside lamp is a customized version of the earliest design, while the tables were entirely new concept. Both were produced using CNC technique for forming the cork. For the additional elements, like tabletops and lamps of steel structure, we engaged the manufacturers that specialized in those materials.

Once again, we were combining the traditional and digital production methods—this time with the purpose of bigger scale. We arrive at the solution where the piece of furniture becomes an integral part of the architectural project connected with its particular location.

The integration of design in various scales was always an objective of Campos Costa Arquitectos. With this and other projects, we are trying to be engaged in the construction process and to develop dedicated solutions.

The ceramic facade of the extension of Lisbon Aquarium, from 2011, is another example that manifests this way of thinking. Ceramics were produced in cooperation with Spanish company Cumella, known for its huge tradition of crafted ceramics.

At that time, using traditional methods of production, we were engaged with the manufacturer in the process of developing a facade solution. We believe that advanced manufacturing methods are helping to facilitate this kind of integration and stimulate unconventional solutions.

Discussion

In our practice, we are always placed between modernity and tradition, on the edge of those two we are searching for the solutions most suitable for given tasks. With the use of advanced techniques, we are seeking for contemporary forms of traditional materials rooted in the local history. Those experiments would not be possible without taking advantage of the knowledge gathered by experienced craftsmen.

Along the last few years, we have been through several experiences based on this integration—many of them successful such as Lisbon Aquarium or Hotel Ozadi and several Caco pieces, some burdened with several failures (still being under process of development), but that is the price and quality of Pye's (1968) "workmanship of risk" or, if you prefer, Kolarevic's (2008) "(Risky) craft of digital making." In this context, we see architecture as a craft—where the knowledge is obtained by making—regardless of what kind of tools are being used.

With above-mentioned examples, we want to emphasize our conviction that there is no contradiction between tradition and innovation, and that traditional craft and advanced technology can be successfully combined together for the sake of high quality design and architecture.

Notes

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CHAPTER TWENTY THREE

CORK RE-WALL: AUTOMATIC GENERATION OF BUILDING INSTRUCTIONS

FILIPE BRANDÃO

Introduction

Computational and parametric design methodologies play a multiplicity of roles in the analysis, visualization, simulation, design, and construction of buildings. These methods are no longer foreign to the processes of design in practice. In particular, recent developments in parametric design are particularly suited to small self-built refurbishments.

Cork Re-Wall (CRW)[1] was developed in order to explore the potential application of computational tools in building renovation.

CRW is a parametrically-modeled construction system and a file-to-factory digital process that responds to diverse renovation design challenges. The construction system is composed of a wood frame structure cut out of OSB panels and composite panels of ICB and plywood. All the parts are milled with a CNC router and assembled together by hand.

The parametric model was developed with two purposes in mind: to simulate the system behavior and optimize it, as well as to provide an interface for design customization and digital fabrication by an end user, either a client or an architect. The construction system was developed for the context of old buildings renovation, which is understood as a set of interventions on built heritage pursued with the aim of improving its safety, comfort, and usefulness that nonetheless respect its architecture, typology, and constructive system. Within that scope, CRW is a solution amongst others that needs to be implemented in order to address the entire set of problems that the context presents.

With CAD/CAM processes of design development, it is possible to translate a digital model into a sequence of instructions for some particular fabrication machine. As Kolarevic states, “the crucial efficiency considerations are, first, the number of operations that must be executed to physically produce a given design, and second, the speed with which each operation can be executed”.[2]

CRW parametric models allow for design variations and automatic generation of production drawings for a CNC router. These variations do not impact the number of design operations or the speed with which a particular machine produces a given design. The number of operations for production or on-site assembly, on the other hand, increase with the size of the wall. Even though on-site assembly is meant to be executed by hand, given the puzzle-like nature of the system’s structure, it is necessary to communicate the assembly sequence steps if the wall is to be built by someone without knowledge of the system.

Instructions for assembling or operating products at home are common. Mass-produced products only require one set of instructions, on the other hand, modular or customizable products require many different versions of these instructions to be produced. Designing clear and easy to follow instructions is a time-consuming and expensive task that requires skilled designers. The complexity and diversity of CRW designs bring significant challenges to producing building instructions. But as Agrawala *et al*.’s work demonstrates,[3] it is possible to automate the process of designing assembly instructions that are clear and easy to follow.

In CRW structural design, the design of the fittings and connections and their assembly sequence are intricately connected and were developed in tandem. In this paper, their underlying design methodology and process are briefly described in order to explain how the constructive system and its assembly sequence were optimized. But the main focus will fall on the methodology and principles of a system to automatically generate design descriptions that can be used as instructions for building CRW parametric construction system.

We describe how these principles can be embedded in the parametric model that generates design solutions.

Background and Related Works

One of the requirements of CRW was to reinstate the use of traditional materials in a context of scarceness of craftsmen knowledgeable of traditional building techniques. In order to achieve this objective, the construction system follows a similar approach to assembly, as is found in Sass's Wood Frame Grammar.[4] All the pieces are friction fit without the need of special connectors to hold the parts of the wall's structure together. All that's required is a rubber mallet to assemble it. The geometry of the connections and the assembly process was developed so that the pieces could be cut with a 3-axis CNC router. As a result, the assembler is not required to have previous construction experience neither is there a need to use professional power tools to assemble the wall. The single requirement to be able to assemble the wall is the knowledge of the steps of the assembly sequence. These steps could be communicated in a written format, with step-by-step actions. Yet communicating them, by means of a series of exploded axonometric views with the least amount of text, is more universal and less ambiguous. In this context, we differ from Sass,[5] the process doesn't negate the use of drawings during the construction stage. Even though the digital process eliminates the need for a designer to produce drawings, the assembly process requires some knowledge about the system assembly sequence to be communicated to the assembler. This knowledge is best communicated through drawn instructions.

Figure 23.1
Image of a CRW wall assembled for CEAAD course final exhibition.

Lego and Ikea are examples of companies that use diagrams to communicate the assembly sequence of their products to their customers. These companies' business model relies precisely on selling mass-produced products that are customer-assembled. One set of instructions can be used to unequivocally assemble all of the instances of each type of product. CRW parametric partition, unlike the previous examples, is non-standard. Each different solution has different assembly sequences. Despite that, there are simple rules that determine the subdivision of the wall and the generation of each one of its components. These same rules could be used to generate assembly instructions that could then be used to assemble the wall itself. These diagrams differ from typical building drawings, 2D plans, sections, or elevations, which require technical drawing knowledge to be interpreted. They are meant to be read by anyone.

Automatic generation of assembly sequences is a thoroughly studied subject, particularly in the realm of robotics.[6] The order in which the parts, or subassemblies, of a product are assembled can greatly impact the efficiency of the assembly task.[7] In an industrial setting, when large numbers of units are being produced, small efficiency improvements might mean large overall capital gains. When a product has more than a few parts, determining the optimal sequence can be an extremely complex computational task. Complicating matters further, different manufacturing contexts might have different optimal sequences for the same product.

These previous works concentrate on planning and optimizing production and generating instructions that are understandable by robots. Another line of investigation on the field of visualization focuses on producing automated presentation design systems.[8] Agrawala *et al.*'s work combines aspects of these two lines of investigation and proposes a system that encapsulates cognitive design principles of human produced assembly instructions.[9] In their work, designing instructions is split in two stages: planning the assembly steps and presenting the steps in a clear way. Even though these stages are resolved sequentially, the planner makes use of the design principles and rules of presentation to determine adequate sequences. The planner uses an extensive search algorithm to determine which sequences to present. This process is computationally expensive and requires complicated input data.[10]

Another line of investigation focuses on generating LEGO assembly sequences that can be followed by children to build LEGO models built by their friends. As it is intended to be used by children, the process must be seamless with play.

A patent application by Prüss, describes a process of generating automated building instructions using a virtual construction environment.[11] A child builds a model using a computer graphic user interface program that records the steps needed to build the model, turning them into a set of instructions that can be shared with friends. This generative process is easy to use but the quality of the instructions needs to be improved. To overcome this issue, Jakobsen *et al*. propose the use of a deconstruction search algorithm, where at least one piece or a subassembly is removed at a time from the model.[12] By reversing the process, a valid assembly sequence is obtained. This method, which Romney *et al*. define as assembly by disassembly,[13] has been widely used in robotics; it starts with the finished product and works backwards until all parts are removed from the starting object. In order to determine which pieces to remove, two processes are used: a disassembly tree or a geometrical approach where faces in contact suggest the directions of freedom of the objects.[14]

The previously referred works have focused either on developing a universal solution to assembly planning problems, where an object can have any shape, any number of parts, and unknown number of assembly sequences, or on objects composed of known parts that can be assembled in limitless compositions.

Our process focuses on an object composed of known parts and assembly sequences, which can nevertheless have multiple configurations. The objective is to automate the process of generating building instructions for CRW walls. In order to achieve this goal, we developed a framework that is presented in this paper.

Cork Re-Wall Building Instructions

Description of the Framework

The investigation was divided into three areas: Design, Material, and Production. In Design, the subdivision grammars and rules were defined and tested for their adequacy to the context of the design problem. The ultimate goal was to develop a parametric model of the construction system that allows its customization and digital production. In Material, the investigation focused on material properties, detailing of the wall, and adequacy of the material solution to the context. Moreover, the assembly process was also conceived.

Finally, in Production, the solutions were prototyped to verify how the selected fabrication process—a 3-axis CNC router,—interacts with the materials and constrains the proposed solutions, as well as to test the envisioned assembly process. Every solution was built according to a predefined plan of assembly to troubleshoot problems with connections or incorrect assumptions in their design. These three areas are intricately connected yet it isn't possible to map the complexity of relations between them. Hence, a top-down design process was adopted to develop the CRW parametric partition wall. To overcome the risk of prioritizing preliminary design decisions, thus conditioning material and fabrication solutions, three cycles of design to production and assembly were performed.

Planning—Design, Material, and Production

Cork Re-Wall parametric wall is made up of a wood frame structure cut out of 15mm OSB sheets with a CNC router and composite panels of 30 mm ICB and 12mm plywood. The connections of the structural parts are friction fit and the assembly is performed manually with a rubber mallet. This process bears several similarities with Sass Wood Frame Grammar (2005);[15] however, its novelty lies in the design of the joints, the dimensioning of the members, and the use of several materials to address different performance needs of the wall. The nature of existing floors, ceilings, and walls of refurbished buildings lies outside the control of this process, so friction fit joints between the wall and the supports aren't possible. Instead, ceiling and sole plates with a 20mm ICB dampening layer are fastened with screws to the ceiling and floor slabs. The same detail is used to connect end studs to supporting walls. The structure parts are numbered and the assembly process proceeds from the floor up and from one side to the other. The composite panels perform both finishing and bracing functions of the wall structure. The finish can be either ICB, plywood, or a customizable pattern of cork and plywood. Standard dimensions of ICB boards (1000x500mm) determined the on-center distances of the studs, which are half the length of the panels. To stiffen the wall, the paneling of the structure is done in a stretcher-like pattern. The length of the studs and blocking is limited to the largest dimension of OSB standard panels. The wall can be of any length, yet the maximum height of the wall was set to 4,60m. The vertical subdivision of the studs is of necessity, both for structural reinforcement and to accommodate the maximum length of standard OSB panels. Three cases of vertical subdivision were defined to strike a balance between cost and structural efficiency. Double vertical studs, simple wall-end studs, ceiling and sole plates are common to all cases, and blockings are added as the height increases.

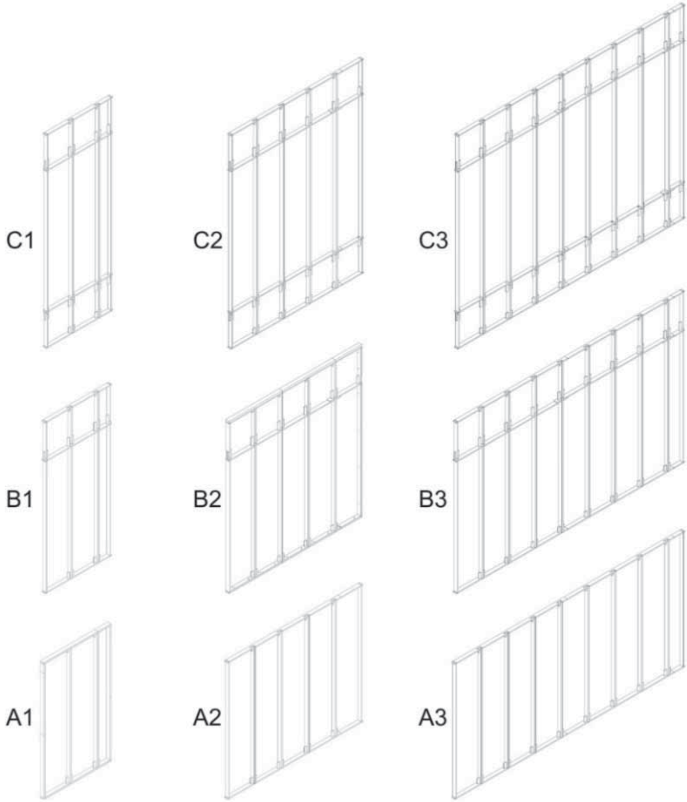

Figure 23.2
Nine cases of CRW parametric wall structures.

The parametric model is a generation, a simulation, and an optimization tool. It provides an interface for design customization and digital fabrication by an end user, be it a client or an architect. It is both a design and an evaluation system that produces accurate 3D geometry, which can be used for visual inspection or simulation purposes, and produces 2D shapes of the pieces, which can be used as toolpaths for production. It also outputs information in the form of spreadsheets about the material needed to produce it and the estimated cost. The model was conceived as an interactive program that poses a sequence of questions to the user: what is the length and height of the wall, what is the desired finishing, are there any baseboards or coving, and lastly what selection and customization of the pattern will be chosen.

Different finishes can be selected for both sides of the wall and a choice of three patterns, which can be customized, is provided: a line pattern, an Ice-Ray lattice pattern, and a Voronoi pattern. A CRW wall could be generated by an end user to create screen walls, to divide a room into two, or simply as a decorative finishing. For this particular application, an online customization platform would be adequate, allowing the user to foresee and evaluate the solution, and order it to be digitally fabricated and shipped to their address for self-assembly.

Assembly

The assembly sequence is one of the results of this development process, and is a mixture of design, experience, and optimization. Numbering and naming the parts is a need that arose from the hurdles of assembling the system. The problem is how to present the assembly steps. The instructions need to clarify the necessary steps and the order in which they must be performed to assemble the wall. To achieve this, step-by-step descriptions were produced for three different lengths of wall, for each different case in height, totaling nine different cases. For each of these generic cases, there are four possible configurations of end wall constraints for partitions dividing two spaces, and the same four configurations with an extra constraint where CRW wall is built against an existing wall. The last set of configurations is the most stringent in terms of degrees of freedom for assembly, and the one where the CRW wall meets both the ceiling and the side walls is the most constrained. The nine different cases were generated, modelled, and digitally assembled for the most constrained configuration, which should represent the necessary steps in the remaining seventy-three cases. Digital simulation was used instead of nine physical models, since it allows simulating the necessary movements, making the assembly process much faster.

Cork Re-Wall partition wall is puzzle-like, so in order for a user to know how to assemble it, he needs to have an overall image of system and images of the different types of parts, their number, and information on how to connect them. But some preliminary information that is common to all solutions must first be provided: a list of the necessary tools, some information about the type of anchor sleeves to fasten the base, ceiling plates, or/and end studs. Then an overall image of the built wall and of the complete structure should be provided, and, after, an image of each type of part provided and their quantity. The last preliminary step is a recommendation to draw on the floor and walls a reference line for the horizontal and vertical alignment of the wall, using the structural members as templates.

The sequence of the next steps can vary widely depending on the height and the width of the wall, changing both the number of steps and the geometry of the parts.

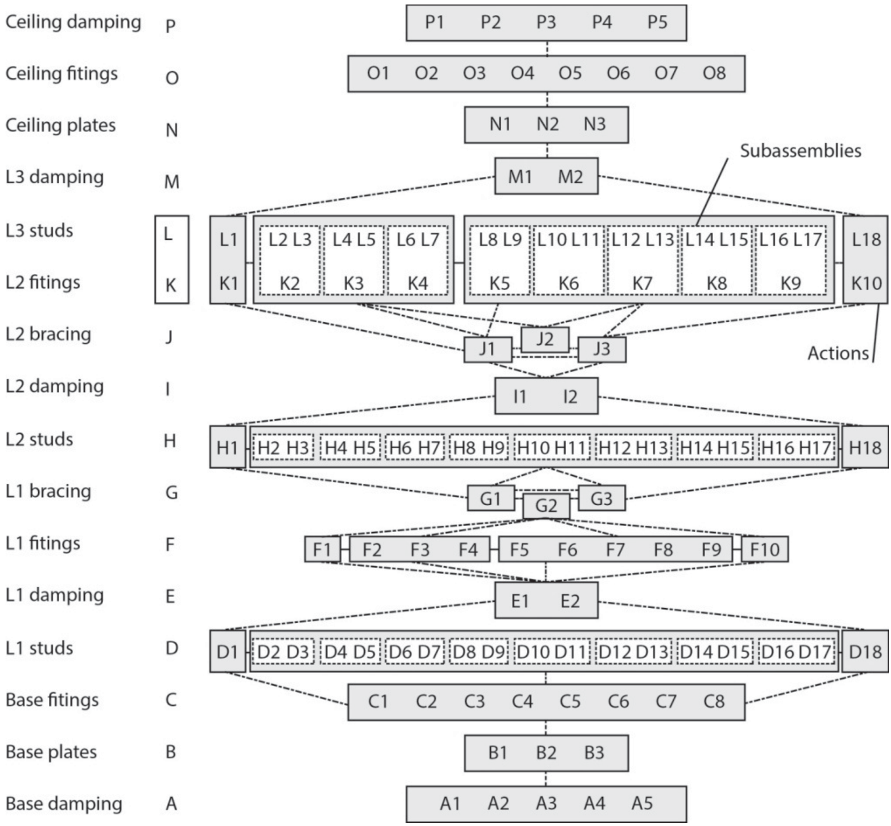

Figure 23.3
Assembly tree of the structure of case C3 (see Figure 23.2).

To deal with the challenge of determining the assembly sequence, we propose a slightly different approach from the previously referred works by generating a hierarchical assembly tree simultaneously with the design solution. The assembly tree would be composed of groups of actions hierarchically ordered that correlate with the object's types and functions in the system. As the height of the wall increases, the vertical hierarchy changes in three steps, represented by the letters A, B, and C. When there is change in horizontal hierarchy, those changes are periodical and easy to model. This hierarchical order is inspired by Agrawala's design principles.[16] Further principles such as: visibility significant features of parts, step-by-step instructions, action diagrams, or natural orientations were also taken into account. Each group of actions can be performed on one or several groups of objects, or subassemblies, contained within or it may also contain actions to be performed on objects that are above it in the assembly sequence. Each action can be described with one or more action diagrams representing how the pieces must be connected. These action diagrams can be either predefined images or generated from the actual model. Using predefined images simplifies the process but, as noted by Jakobsen and Agrawalla,[17] it might not produce high quality instructions for humans, since the proportions of individual pieces might change from one design to another.

On the other hand, each action group contains many objects to which similar actions must be performed. Repeatedly displaying the same action would make the instructions too long and tedious to follow. Presenting them simultaneously runs into another problem. As size of the wall increases, the scale of the representation must also increase, since it is constrained by the medium of presentation, making details too small to be understood. To solve these problems, we propose a solution in which an overall image is presented and next to it the actions are presented in detail. The overall images present the sequence of assembled states, highlighting the added pieces in each step. The details depict how the actions must be performed.

CRW parametric model has a C# algorithm that generates the parts of the system's structure. Each part is an object with properties such as its position, geometry, and type. Any specific part can only be inserted in a given position in the system, in a predetermined sequence. All assembly sequences in CRW are binary, they only require two hands to be performed, and monotone, and once two pieces are connected no further movements are required to the pieces' relative positions for further assembly steps. All parts can be connected with no more than two movements and all movements are limited to the three major axes.

This information can be included in the objects' properties to be used by a disassembler algorithm that generates the overall images from the model and illustrates the actions to be undertaken with predefined detail images. The disassembler follows the assembly tree from top to bottom and reverses the order of the sequence it produces.

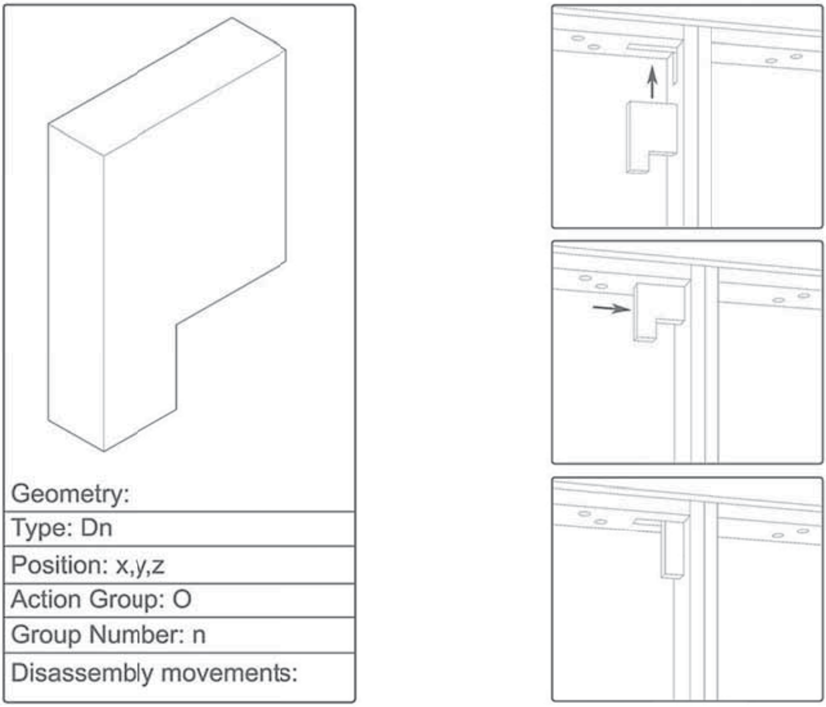

Figure 23.4
Object Properties and actions that assemble it.

Discussion

We presented a framework to automate the process of generating building descriptions of Cork Re-Wall parametric wall designs. The proposed framework is composed of an assembly tree, a disassembler, and a presentation layout. The following goal is to implement this framework in Grasshopper environment, which was used to develop CRW parametric model.

To determine the effectiveness of the envisaged instructions, these must be presented to a group of people without any knowledge of CRW. Future steps are also planned to ask a group of users to customize solutions to their liking and physically assemble them with the generated instructions.

There is another alternative of presenting the overall images of the assembly steps, in which the pieces that are being added are displaced from the main assembly, such as in the action diagrams. To produce these images, the disassembler algorithm must move these objects using the disassembly movements or vectors included in the objects properties. Although more difficult to implement, it must be tested to see if it produces easier to follow instructions than the proposed method.

Notes

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16. Agrawala, "Designing effective step-by-step assembly instructions."
17. Jakobsen, "Automatic generation of building instructions for building element models;" Agrawala, "Designing effective step-by-step assembly instructions."

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LIST OF CONTRIBUTORS

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