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Research

Measuring Lisbon Patterns: Baixa from 1650 to 2010

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Abstract. The present study, based on a comparative analysis of several plans for Lisbon's Baixa district, with an emphasis on that area's public space, contributes to an understanding of the urban design process and presents a fresh perspective on dealing with historical data by conducting a posteriori analysis using mathematical tools to uncover relations in the historical data. The nine plans used were quantified and evaluated in a comparative manner. While CAD was used to quantify the urban morphology of the different plans, comparative tables make it possible to register the data, which was further evaluated through two interrelated processes: mathematical analysis and the urban analysis. The results show the existence of power law relations for the areas of each of the city's different elements (e.g., blocks, churches, *largos* and *adros*). We discuss how this contributes to the understanding of the plans' elements.

Keywords: urban design, design analysis, design theory, CAD, computer technology, morphology, patterns, proportion, measurement, mappings, geometry analysis, fractals, graph theory, statistical analysis

1 Introduction

A city study cannot be separated from the ways in which people live in the city. The ways that people make use of public space are not totally predictable at the architect's drawing board. However, although the reactions of a city's population to its urban complexes might be unpredictable, some almost universal rules exist that allow architects to draw the contemporary city and these rules are already present in the cities of the Enlightenment. Today, thanks to the evolution of science, it is possible to create virtual systems that allow us to project and explore the possible outcomes of the population's reaction to a specific public space. The reaction of populations is then a result of the interplay between different components of the city. From this interplay, the complex dynamics of the urban form emerges.

Having these concerns in mind, the present paper will evaluate the Baixa area of Lisbon, which has been subject to several plan proposals from the period of the Enlightenment time up to the present day. Furthermore, this paper will examine how this public space has performed over time.

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2 State of the art

The nine plans that are analyzed in the present paper refer to four different historical periods: Renaissance, Enlightenment, Modern, and Present-day. Nevertheless, the plans of the Modern period and the Present-day are based upon the chosen eighteenth-century plan.

In the eighteenth century, Portuguese Prime Minister Pombal demanded that Manuel da Maia, the Portuguese Kingdom's principal engineer, to establish rules for the reconstruction of the city of Lisbon after the 1755 earthquake [Sampayo and Rodrigues 2009; Marat-Mendes 2002]. To accomplish this, Manuel da Maia prepared a three-part dissertation indicating five ways to reconstruct the city. The selected approach recommended that the Baixa reconstruction should be situated exactly in the same place, but according to a new plan.

Two sets of rules for the reconstruction of Baixa were established in the third part of Maia's dissertation: One rule obliged the plan proposals to localize the churches exactly as they were before the 1755 earthquake and a second rule granted freedom to the plans' proposals regarding the location of the churches [Sampayo and Rodrigues 2009].

The plans for Baixa have been exhaustively analysed by researchers in different fields, including historians, architects, urbanists, and lawyers. Nevertheless, their research studies have been performed in an isolated manner. For example, França [1987] and Tostões and Rossa [2008] have analysed Baixa from an historical perspective. Heitor [1999] and Kruger [1998] applied a space syntax analysis to evaluate the urban form of Baixa. Mullin [1992] used an historical and political analysis to show the social mark that would be made by the newly restored city of Lisbon. Moreira [1993] aimed to define a conservation proposal for the Baixa and develop a replicable method of analysis for urban conservation. Monteiro [2010] studied Baixa in terms of the legislation produced during the eighteenth century and its influence on subsequent urban legislation. Lopes dos Santos analysed the construction technologies used to renovate Baixa and its relevance is shown [1994] by his analysis of the urban form.

Literature on the analysis of urban form also embraces diverse fields. The following section is divided into two main parts. The first part discusses the analysis of urban form from historical, physical, and morphological perspectives, while the second part addresses the mathematical analysis of the elements of urban space.

The analysis of urban from

a) The historical and physical perspective

Research into the development of cities during different historical periods constitutes an important contribution to the analysis of urban form. Thus, it is important to stress that the use of historical analysis does not represent an intention to replicate the past, but rather to provide the foundation for both preservation and innovation. Understanding the urban arrangements that have worked well, or that have produced beneficial effects in the past, provides important lessons for the future.

According to Marat-Mendes [2002], people's interactions with their environment not only constitute an area of research interest for sociologists or historians, but is also a growing area of interest for researchers of urban form. This is evidenced in Rapoport's [1990] explanation of people's interactions with their environment, Kevin Lynch's [1981, 1996] studies of people's images of cities, and Moudon's [1986] analysis of

people's interactions within the built environment in residential San Francisco. Furthermore, the analysis of environment behaviour has also been enriched by Rossi's [1983] analysis of the processes shaping the urban environment and the work of brothers Léon and Rob Krier [L. Krier 1979; R. Krier 1979], who favoured the re-creation of an eighteenth and nineteenth century grid-planned European city by focusing their rhetoric on the importance of tradition. Indeed, this search for an historical understanding of how urban fabric is shaped over time, and in a comparative manner, is reinforced in the present work's argument for the need to obtain a better understanding of the common processes that have shaped this urban fabric.

However, from the works identified as relevant for the study of urban form, it is evident that different authors use different methods. Papageorgiou's book, *Continuity and Change. Preservation in City Planning* [1971], reveals an interesting analysis of historical centres, while stressing the importance of rehabilitation and conservation. It also recognizes the value of cultural heritage for the survival of historical urban centres. Of particular relevance to the present work is Papageorgiou's acknowledgement of the importance of reading urban space through its multi-layered urban formations. Moreover, he identified the occurrence of change in the urban fabric as the way in which historical urban centres become lively urban spaces with a special kind of atmosphere, i.e., places that provide quality of life to their inhabitants.

Moudon's *Built for Change* [1986] presents a specific case study that analysed the evolution of a residential neighbourhood around Alamo Square in San Francisco. This study addresses the history of that neighbourhood, from its origins in the nineteenth century up to the 1970s, by examining the interactions between different elements of urban form. While making use of historical sources to identify the historical patterns that shaped that particular neighbourhood, the study also promoted an examination of the interaction between people and environment. According to a later study by Moudon, urban form can "only be understood historically since the elements of which it is comprised undergo continuous transformation and replacement" [1997: 7]. Although Moudon's and Papageorgiou's studies differ in scale and nature, they seem to find common ground in the methods they used to understand the different processes that shape urban form. These methods are based on an historical analysis that accepts that changes in urban form occur in multi-layered formations that continually undergo transformations and replacements.

Regarding the historical analysis of urban form and the processes of transformation and replacement that occur within it, Morris [1994], in his historical account of the history of urban form from its origins to the Industrial Revolution, describes the physical results of some 5000 years of urban activity. He constantly cites the socio-economic constraints or political issues that relate to the formation, alteration, or adaptation of the urban forms. Although Morris's analysis is very extensive in terms of the number of cases analysed, he does not provide a comprehensive analysis for each case. Nevertheless, he provides important contributions to the perceptions of what, in this paper, is described as 'lessons from the past.'

Yet, the lessons from the past must not be misunderstood by a single reading of historical urban places. They should also include a re-examination of recent and implemented urban proposals that have proven to be successful. Thus, a historical survey should always be included in any physical analysis of urban form, either to learn about past successes or to understand the forces that have shaped the urban form over time.

The present work sees the dual process of analysis as essential to the determination of liveable and enjoyable urban places for its citizens.

b) The urban morphology perspective

In her comparative analysis of three historical examples of planned urban development, Marat-Mendes [2002] aimed to identify some practical reasons for sustainability. The historical examples cited included the urban development of Lisbon's Baixa by Eugénio dos Santos and Carlos Mardel in 1756, the development of Edinburgh's first New Town by James Craig in 1767, and the development of Barcelona's Ensanche by Ildefonso Cerdà in 1855. Marat-Mendes's work has contributed to the analysis of urban form and its transformations by identifying interest in the perspective of urban morphology, namely by acknowledging the work of geographers such as Conzen [1960] and Whitehand [1981, 1990, 2000, 2001] who contributed to the refinement of morphological studies, with specific analysis on British medieval cities.

According to Whitehand [1981: 17], Conzen's most significant contribution rests on the fact that the evolution of the urban fabric results from progressive physical processes. However, to identify these progressive physical processes, a need exists for a "detailed examination in genetic terms of street and building lines, building block plans, and the shape, size, orientation and grouping of plots (lots)" [Whitehand 1981: 17]. Carmona et al. [2010] state that Cozen has worked these components, while considering them as key elements in the analysis of urban form.

Conzen's and Whitehand's morphological studies have been utilised in other disciplines, such as in Samules' [1993, 1997, 1999] works on architecture. Urban morphology analysis has also been followed with interest in Italy, where it was first approached by Muratori [1959], giving rise to new areas of urban research, such as urban typology. Muratori was one of the principal initiators of urban typology and renamed it Procedural Typology. This consisted of a morphological analysis of towns where special attention was given to building types as the elemental root of the urban form and where evolution was the main topic. The "notion of evolution was therefore invoked as a means of gaining a better understanding of the built environment" [Kropf 1998: 45].

In the late 1960s in France, the interest in morphology and typology attracted architects Phillipe Panerai and Jean Castex and the sociologist Jean-Charles DePaule. However, their contribution to building typology was less important than their contribution to the deeper analysis of the city block [Castex et al. 1977].

Other contributions to the morphological analysis of urban forms have focused on the evolution of street layouts and block form. In this area, Sola Morales and the 'Grupo 2C' have contributed to urban block analysis, devoting special attention to the time between the medieval period and the nineteenth century. Their principal case study focused on Barcelona's urban fabric. In 1978, *Lotus International* dedicated an entire issue to this specific subject. Issue no. 19 of this journal included several studies of urban blocks, such as the Sola-Morales' [1978] study of the evolution of the blocks in Barcelona, and Léon Krier's article, "Fourth Lesson: Analysis and project of traditional urban block" [1978]. Krier's study underlined the importance of the return to traditional urban patterns of blocks, streets, and squares as fundamental elements of urban form. He proposed the analysis of these urban elements based on historical or 'traditional' models of the European city.

Not only has the return to traditional urban patterns and sizes been claimed as essential to the urbanisation of urban spaces, there are also indications that the way urban

forms are analysed has changed and need to be reoriented towards traditional methods. According to Siksna,

> A further limitation of the recent studies and applications of the block is that they have confined their attention to the relationship of built form, street space and internal courtyard space. Most block developments are conceived, and carried out, as comprehensive schemes for the entire block, rather than the traditional manner of individual buildings on separate lots. Thus the block has been revived essentially as an urban form of buildings and spaces, but not as a layout form of lots, blocks and streets [Siksna 1990: 2-8].

Thus, Siksna gives preference to the analysis of urban forms by using the urban block as a key unit of analysis. He claims that the practice of conceiving urban blocks needs to be rethought and he proposes an analysis of the traditional methods of block arrangement.

So far, this review of studies on the physical analysis of urban forms has focused on traditional urban patterns and the preferred methods of urban analysis. Therefore, both perspectives seem to agree that the urban fabric needs to be analysed using historical methods because the city cannot be studied separately from the processes of change to which it is subjected [Moudon 1997].

Despite the existence of a significant number of works on analysis of urban form, the relationship between urban elements and the processes that enabled change appears to be an area of investigation that has not been fully explored. According to Moudon:

> … the rate of change in either the function or the form of the cells varies from city to city, but also generally fits into cycles related to the economy and culture. Building and transformation cycles are important processes to explore for city planning and real estate development proposes, yet are rarely studied in contemporary cities [1997: 7].

This lends support to the validly of the use of the comparative analysis of urban form in this work, wherein the same area of the city is studied in reference to different historical periods.

Mathematical analysis of urban spatial elements

The study of the city can be conducted at different levels by abstracting features and using different tools. Graph theory was first applied to solve an urban problem in 1735, when Euler [1741] used it to solve the problem of the Königsberg bridges. In the 1980s and 1990s, space syntax revitalized the use of the graph theory for measuring city features [Hiller and Hanson 1989]. One aspect of this theory, of particular interest to this study, is its use of the term "iosvist" to define the volumes of space seen from a point in the city [Benedikt 1979]. More recently, Agent-Based simulation has gained particular interest because it is not possible to account for some non-linear features with traditional reductionist approaches [Batty 2007]. The non-linearity of the social aspects of life systems is also manifested in cities and the mathematical analysis of urban spatial networks and can be seen in Blanchard and Volchenkov's [2008a, 2008b] work on random walks. Random walks defined on graphs, and their very closely related diffusion processes, have been studied in detail. The random walk hypothesis was used successfully in several fields of research such as economics, where it was used to model share prices, and population genetics, where it was used to model genetic drift [Blanchard and Volchenkov 2008b].

Miller [1978] compared the city with a biological entity that shares several physiological characteristics with biological systems scale, such as the mass of their bodies (M). The power P_w required to sustain a living organism has been shown to scale according a power law, such as:

$$P_w \propto M^{3/4} \qquad \text{(eq. 1)}$$

This characteristic (features obeying some power law distribution) has also been observed in many aspects of cities [Savage and West 2006]. Zipf [1949] showed that the population of a city depends only on the size of the largest city and the rank of the city.

In effect, power laws have been found in several domains of human activity. From the World Wide Web to genetic pathways, this law, which affects all scales of observation of the objects, is pervasive and constitutes a fundamental feature of human activities.

In this sense, we analysed the areas of different elements of Baixa, including the block area, the church area, and the *largos* e *adros* areas. We found that these areas also obey characteristic power laws.

3 Case study and methodology

Case study

In this paper, the case study analysis refers to Baixa, Lisbon's downtown area. Several plans were used in order to make a comparative analysis possible, including the pre-earthquake plan by Tinoco (1650), the plans 1 (Pedro Gualter da Foncêca and Francisco Pinheiro da Cunha), 2 (Elias Sebastião Poppe and Jozé Domingos Poppe), 3 (Eugénio do Santos de Carvalho e António Carlos Andreas), 4 (Pedro Gualter da Foncêca), 6 (Elias Sebastião Poppe), and the "Chosen" plan[1] (missing), proposed for the reconstruction of the downtown in the aftermath of the 1755 earthquake (1758). We also considered the E. Gröer 1948 proposal for the transformation of Baixa's urban blocks, and the built or Present-day plan for Baixa (2010).

Concepts

This research has considered Public Space as the sum of two main urban morphological elements. One use of the term public spaces refers to the circulating spaces (streets area) and the other use refers to the permanence spaces[2] (squares, churchyards or *Adros* and *Largos*) [Pereira 1983]. Thus, for its analysis, this research will consider the following principles:

- 'Public Space' – The sum of Streets, Squares, and *Adros and Largos* areas
- 'Permanence Space' – The sum of Squares, and Adros and Largos areas

A short definition of the Permanence Space terms is succinctly provided as follows:

- 'Squares' – A geometrical space, bordered with houses or rivers on each side, usually with public buildings on these edges.
- '*Largos'* – A Portuguese term used to designate an informal square.
- '*Adros'* – A Portuguese term used to designate an open space situated in front of a church.
- 'Residual Voids' – Urban Voids that cannot be classified as public spaces and that do not have any useful purpose.
- 'Block Area' –The sum of the built area and the inner courtyard area.

These definitions, although useful, are insufficient for grasping the concepts in their entire scope. The interplay between these elements is richer and more useful. The following explanations attempt to elucidate a deeper understanding of their relations.

Squares refer to public spaces with a well-defined (Euclidean) geometry, which result from the addition or subtraction of different volumes, and which present different uses that respect the use of a square.

The square is a public space *par excellence*, as are the street, the avenue, and the alley. The street acts as a flowing space while the square acts as a space of interaction. Thus, the square functions as a space of permanence associated with the functions that are present within it. The *largo* differs from the square. Therefore, the *largo* is generally the result of the exploitation of a residual urban space and presents mostly irregular forms with diverse sizes. The *largo* might emerge from the need for a void or a crossway. However, it does so in a spontaneous form and not in a previously planned form as would occur in a square. The square's space is rigid and defined by rules; it has functional order constraints while the purposes of the *largo* are not as clear [Sampayo 2007].

The consolidation of the square as the power headquarters of the city, as an ordered space and as a planned infrastructure, only emerged during the seventeenth and eighteenth centuries.[3] According to Sampayo [2007] the plans for medieval Portuguese cities obeyed the criteria used for regular tracing, but these plans did not include defined urban squares. Empty spaces existed near the city's walls but these were not structured. Today, if we find structured medieval squares within medieval cities, these are the result of prior transformations. During the reign of Portuguese King Manuel I, at the end of the fifteenth century and beginning of the sixteenth century, institutional reforms with urban concerns were instituted, particularly with regard to the creation of regular squares associated with the construction of new civil and religious buildings. However, the eighteenth century inherited this cultural past and it is during that time that the square, as a public space, was designed in accordance with a geometric structure and within this framework one can trace the evolution of public space within the city [Sampayo 2007].

Françoise Choay, an urban and architectural historian from the University of Paris – VIII claims that the history of the public square can be written throughout the history of urbanization and of power, revealing chronological discrepancies as well as morphological differences among different countries. Therefore, she divides her analysis [Choay and Merlin 1988] into three main stages. The first stage refers to the Medieval Era, from the eleventh century until the end of fourteenth century; the second stage refers to the period from the Renascence Era until the Industrial Era; and finally, the third stage refers to the era in which industrialisation flourished.

According to Choay and Merlin [1988], during the Medieval Era, very few squares existed in cities outside of Italy. In Paris, up to the reign of Henri IV only one square can be identified. Thus, public life used to take place in the streets. The tiny churchyards, located in front of the churches and cathedrals, have not, thus far, earned the distinction of being designated as squares.

Nevertheless, during the Medieval Era, it is important to identify two exceptions: the squares situated over the forums of the former Roman foundations; the arcaded squares that occupied several modules in the centre of the orthogonal grid and that usually joined a church and a commercial area in the city centre (as in France in Montpazier, Villeréal), and the squares in fortified cities and in new cities such as Zähringen in Switzerland. These examples testify to the existence of squares in planned medieval cities, known as Bastides, which were also established in Portugal.

During the second stage, and primarily due to Italian influences, an aesthetic square emerges. The aesthetic square did not serve a functional purpose. Instead, the principal propose of the aesthetic square was to embellish the city and convey an image of power. The aesthetic square was no longer a product of a municipality or a collective; instead, it was a final product of architects, promoters, and urban art.

The third stage is marked by the flourishing of the Industrial Era in which public life took place in the interior of public buildings; such as markets, theatres, etc. During this period, the public space was invaded by the means of transportation.

As previously noted, the concept of the square evolved over time and is strongly associated with specific periods of our history.

The notion of public space also emerged very late in time and has been dealt with in different ways by different authors of urban studies. Léon Krier [1999] envisioned the public space as a fraction of a specific urban environment that defines the lifestyle of the society that inhabits it. In this sense, Krier believes that public space should comprise between 25% and 35% of the overall plan of a well-determined urban design morphology.

The methodology

As referred to in the previous work of Sampayo and Rodrigues [2009], research in the Portuguese urban cartographic archives has revealed the existence of several copies of the same plans with subtle differences. The following four plans can be found in the "Gabinete de Estudos Arqueológicos da Engenharia Militar"(GEAEM), although França [1987] has indentified five plans during the 1960s, meaning that one of the plans is missing [Sampayo and Rodrigues 2009]: Plan 1, Plan 2, Plan 4, and Plan 6. The following plans can be found in the City Museum: Plan 1, Plan 2, Plan 3 (two identical versions), Plan 4, Plan 6, as well as the plan for downtown before the earthquake.[4]

Sampayo and Rodrigues [2009] already noted the existence of two or more copies of the same plans. They also indicate the existence of slight differences in these copies. However, ongoing research, led by Sampayo, is conducting a deeper analysis of this occurrence. Moreover, it is important to stress that the eighteenth-century cartography, analyzed in the present article, does, in fact, refer to the plans that are found in the City Museum in Lisbon.

The methodology adopted for this paper followed the following steps:

1. Delimitation of the area of study. Approximately the same area (51 hectares) was considered for all nine plans.
2. The plans were digitalized and rescaled to the same scale to allow for the comparison of components contained in the nine analyzed plans.
3. The digitalized plans were transformed into vector format in order to allow for the measurement analysis of their urban from elements. The analysis was realized using the AutoCAD tool.

   Seven of the nine analyzed plans refer to the eighteenth-century cartography that was digitalized from the City Museum original plans. The two other plans are the 1948 plan for Baixa by the French architect-urbanist Ètienne de Gröer, and the Present-day plan for Baixa. All nine plans were analyzed in a comparative manner through AutoCAD.
4. The comparative analysis was based on the following elements: churches, noble buildings, squares, urban blocks, and permanence areas.

5. Each of the different plans was then analyzed for the size distribution of each of the different components of interest: block areas, church areas, *largos* and *adros*. Furthermore, statistical data derived from the resulting features was compiled and further analyzed to provide insights into how these features interacted in the city urban form. From this, we obtained several explanative correlations.

4 Results and analysis

Area distribution of urban elements

We analyzed the size (area) distribution of the several urban elements included in the different Baixa plans, including block size areas, church areas, *largos* and *adros* areas. These three features were examined only for the chosen area of study. It was observed that some of the elements of the urban fabric obey a characteristic power law distribution in terms of occupied area. This means that the area of a feature only depends on the biggest feature of the same type and on the rank that it occupies according to:

$$A_n \propto A_1 n^{-\alpha} \qquad \text{(eq. 2)}$$

where A_n is the area of feature of rank n, A_1 is the area of the biggest feature (rank 1), and α is the characteristic exponent that characterizes the decay of the power law.

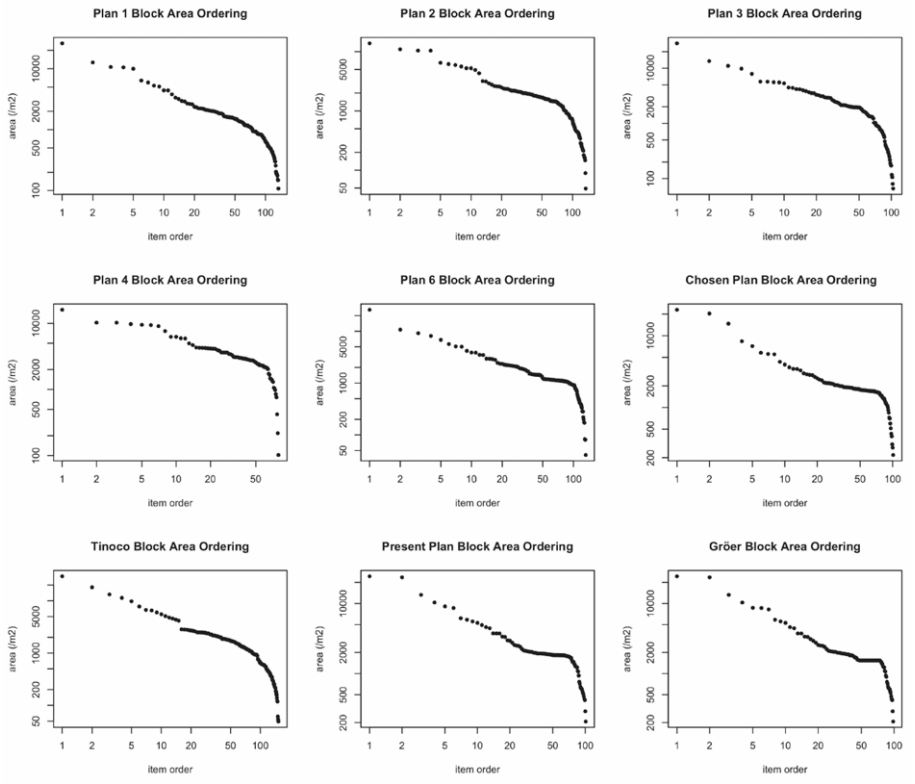


Fig. 1. Block area ordering for the several plans shows a power law dependency throughout most of the ordering range

Block area ordering

The urban block implemented area was the first feature studied. We observed a power law distribution with an exponential decay $\alpha \cong 0.6$.

Fig. 1 shows that the area of the blocks of the city decays according to a power law in several plans, although not all the blocks decay in the same way. This behaviour is verified up to blocks of rank 60-80 in the different orderings when, due to the lack of usable area, the block areas decrease abruptly (cut-off point). These high rank blocks are numerous and tend to occupy the voids left by the existence of big blocks in the city. As can been seen, up to 20% of blocks fall into this cut-off segment. Similarities can also be observed in the behaviour of the ordering between Plans 1 through 3, and in the Tinoco plan, while obvious similarities exist between the Chosen plan and the Present-day plan and between the Chosen plan and the de Gröer plan.

Table 1 shows the values of the characteristic decay for the different block sizes. The values are in the range of 0.50-0.73, a bit smaller than the Zipf law ($\alpha = 1$), but an admirable consistency exists between them. Zipf first formalized the rank sized rule suggesting that the size of cities' Pr scales should be based on the size of the largest size P1 and its rank r in Pr = P1 / r. Notice that this is the same expression as seen in Eq. 1, with $\alpha=1$.

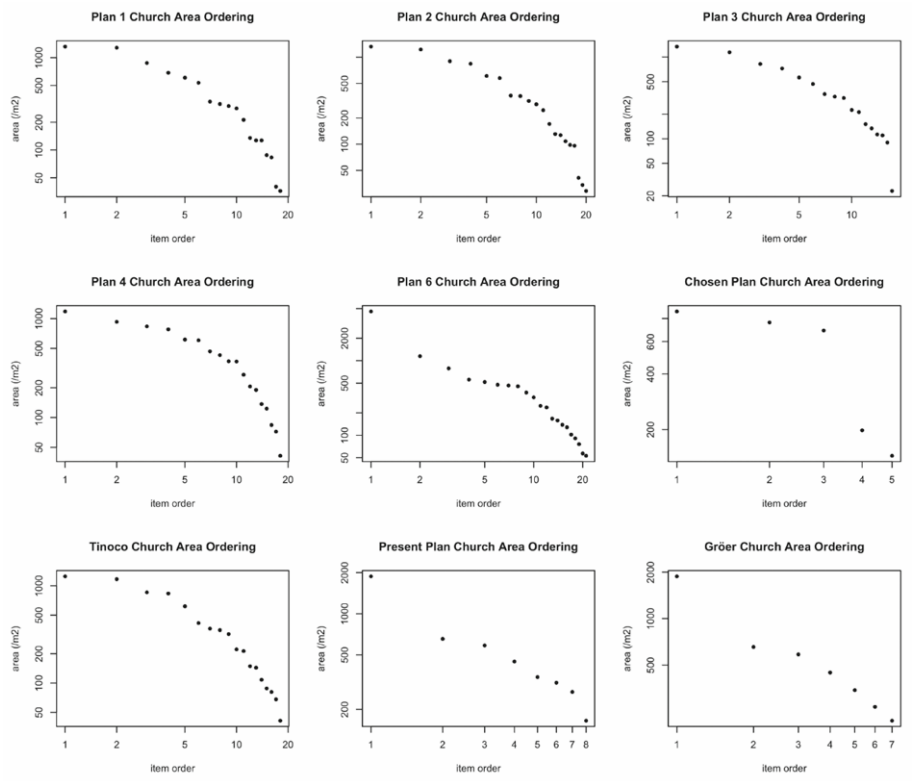


Fig. 2. Church area ordering evidencing the exponential decay of the areas

Church Area Ordering

For the church area, fig. 2 shows that the area rank distribution does not fit a power law, in all cases. This is probably due to the space constraints of the urban fabric. It is observed that in Plans 1, 2, 3, 4, and 5 and the Tinoco plan, the church area clearly approximates an exponential distribution more similar to the cut-off zone. This observation that the church occupied areas decay more quickly than the general block trend is due, most likely, to their special function in the urban fabric, as church occupied areas could support small-sized elements, such as small chapels in the small voids of the city. The present-day church ordering plan and the Gröer plan, with their small number of churches, seem to provide evidence for a closer power law relation rather than an exponential one.

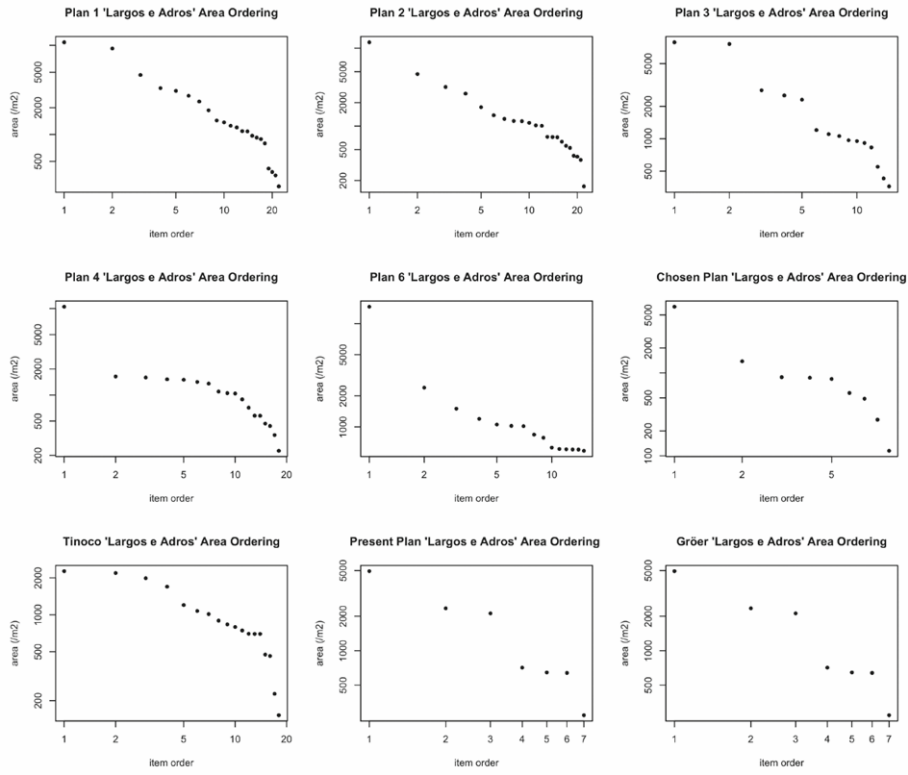


Fig. 3. *Largos* and *adros* area ordering shows the power law decay in some plans, while in others it is closer to an exponential decay in the area

Largos *and* adros *ordering*

Observing the *largos* and *adros* data, we see that no clear single distribution is evident. While in Plan 1 and 2 (and to some point in Plan 3 and the Tinoco plan) the ordering of the areas of *largos* and *adros* is based on the power law, while on the remaining plans we find different behaviours. It is also important to notice that the behaviours of these curves seem not to be coupled with the church areas orderings, although some *largos* and *adros* might be part of churchyards. In general, the area decay seems to indicate that a power law rule governs the distribution of areas as opposed to the

church area distribution seen in fig. 2. This can be easily observed in fig. 3, where the decay of the areas seems to more closely resemble a straight line in the log-log plot. In general, this observation suggests that the data presents a great variety of power law exponents, ranging from 0.5 to 1.2. For some series, as can be seen in the case of Plan 1, the law of exponential decay is clearly obeyed, while in other cases, such as the Chosen plan, this behaviour is not shown. This observation makes it difficult to extract a common rule about the *largos and adros* occupancy of the city in these plans and one needs to take a detailed look at each one of them.

Summary Tables

Tables 1-5 show data obtained from the implementation of the five points stated in this paper's methodology section. Several interesting observations can be made about this data.

The total area of the study is, on average, 51 hectares, of which 49 hectares are of land area, while the remaining area is due to the Tagus River (Rio Tejo). The land area is segmented according to Tables 2, 3, 4, and 5. Table 2 provides a synthesis of the land area's constituents. Tables 3 and 4 decompose the public space and the block areas of the city, respectively. Finally, Table 5 shows the primary relationships between the two main squares of the city in each of the nine plans studied.

Table 5 shows, in percentage, the areas of each plan in relation to the present. The last line shows the relationship between the areas of the two squares in each plan.

Discussion of the Summary Tables

Before beginning the discussion, the reader should note that these tables should be read together with the vector images of the plans in the appendices.

As mentioned, the overall area in analysis is approximately 51 hectares. This value represents the average area of the different plans analysed. This is because each of the nine plans in the analysis presents different scales. As a result, many calculations were required so as to determine the distance between specific buildings that did not suffer any adjustment with the 1755 earthquake. The 51 hectares covered the land areas indicated in the plans, such as river areas. This is an important distinction to identify because the coastline is different within the different plans. The Present-day plan and the de Gröer plan present a larger land area because the river area was not included in these plans, as several landfills have been implemented over the course of the time periods investigated.

From Table 1 it is possible to ascertain that the Tinoco plan presents the lowest area of public space (27%) and that it represents about half of the area available in the de Gröer Plan (50%). This is understandable if one perceives the urban morphology in use in each of these two plans. The morphology in the Tinoco plan is tighter and represents narrower streets. The morphology in the de Gröer plan benefit from wider streets and a larger amount of street area (including the stress in the inner areas of the urban blocks) as compared to the Tinoco plan and other plans analysed.

If one excludes the two main squares in the accounting of public space in the de Gröer plan and the Present-day plan (squares Praça da Figueira and Martim Moniz do not exist in the other plans), it is possible to verify that the public space areas, in the plans proposed for Baixa and in the plan area, are similar, varying between 37% and 46%. However, Plan 6 presents the highest amount of public space, supported by the squares area rather than the street area.

	Tinoco	*Plan 1*	*Plan 2*	*Plan 3*	*Plan 4*	*Plan 6*	*Chosen Plan*	*de Gröer*	*Present Plan*
α	0.61	0.67	0.61	0.64	0.50	0.73	0.65	0.72	0.67

Table 1. α for the block size distribution for the different plans is similar among plans

	Tinoco	*Plan 1*	*Plan 2*	*Plan 3*	*Plan 4*	*Plan 6*	*Chosen Plan*	*de Gröer*	*Present*
Land Area /ha	**47.7**	**46.4**	**49.8**	**47.8**	**48.3**	**47.6**	**43.8**	**55.2**	**55.2**
Public Space	27%	37%	40%	41%	41%	46%	40%	50%	47%
Block Space	62%	54%	49%	53%	59%	50%	59%	48%	51%
Residual Voids	11%	9%	11%	5%	0%	4%	1%	2%	2%
	100%	100%	100%	100%	100%	100%	100%	100%	100%

Table 2. Distribution of the land area by the elements of urban form

	Tinoco	*Plan 1*	*Plan 2*	*Plan 3*	*Plan 4*	*Plan 6*	*Chosen Plan*	*de Gröer**	*Present**
Land Area /ha	47.7	46.4	49.8	47.8	48.3	47.6	43.8	55.2	55.2
Public Space (a+b)	**27%**	**37%**	**40%**	**41%**	**41%**	**46%**	**40%**	**50% (45%)**	**47% (42%)**
a) Street Area	48%	45%	56%	51%	50%	65%	59%	66% (74%)	64% (72%)
b) Permanence Space Area (b1+b2)	52%	55%	44%	49%	50%	35%	41%	34% (26%)	36% (28%)
b1) Squares	*38%*	*26%*	*25%*	*33%*	*36%*	*22%*	*35%*	*30% (22%)*	*32% (23%)*
b2) 'Largos' e 'Adros'	*14%*	*29%*	*19%*	*16%*	*14%*	*13%*	*7%*	*4% (5%)*	*4% (5%)*

* In parenthesis, the values obtained when the squares of "Figueira" and "Martim Moniz" were excluded

Table 3. Decomposition of the public space in its elements

	Tinoco	*Plan 1*	*Plan 2*	*Plan 3*	*Plan 4*	*Plan 6*	*Chosen Plan*	*de Gröer*	*Present*
Land Area /ha	47.7	46.4	49.8	47.8	48.3	47.6	43.8	55.2	55.2
Block Area (a+b)	**62%**	**54%**	**49%**	**53%**	**59%**	**50%**	**59%**	**48%**	**51%**
a) Residential/Others	79%	79%	78%	82%	83%	84%	73%	91%	85%
b) Notable Buildings (b1+b2)	21%	21%	22%	18%	17%	16%	27%	9%	15%
n. Notable Buildings	*24*	*25*	*26*	*22*	*25*	*26*	*13*	*10*	*13*
b1) Civil Buildings	18%	18%	18%	15%	14%	11%	26%	7%	14%
n. Civil Buildings	*6*	*7*	*6*	*5*	*7*	*5*	*8*	*3*	*5*
b2) Church Area	2%	3%	3%	3%	3%	5%	1%	2%	2%
n. Churches	*18*	*18*	*20*	*17*	*18*	*21*	*5*	*7*	*8*

Table 4. Decomposition of the block areas in its elements

	Tinoco	***Plan 1***	***Plan 2***	***Plan 3***	***Plan 4***	***Plan 6***	***Chosen Plan***	***de Gröer***	***Present***
Ratios									
Rossio/Present	82%	79%	84%	80%	109%	81%	99%	100%	100%
Terreiro do Paço/Present	114%	99%	117%	171%	83%	89%	105%	100%	100%
Terreiro do Paço/Rossio	2.2	1.9	2.2	3.3	1.2	1.7	1.7	1.6	1.6

Table 5. Analysis of the main squares of the different plans

From the nine analysed plans, it is possible to verify that seven of the plans present public space area that occupies between the 40% and 50% of the plans. Only Plan 1 and the Tinoco plan approximate Krier's ideal values for public space. Krier says that public space should occupy between 25% and 35% of the plan; however, both Plan 1 and the Tinoco plan deal with a very different morphology than the public spaces proposed by Krier, so the percentages could be assumed to be different. In the case of the analysed plans for Lisbon's Baixa area, the distribution of the permanence areas is not uniform. The biggest areas of public space are concentrated on the edges of the studied area.

Even though the percentage of public space area is higher in the de Gröer plan (50%) than it is in all the other plans, the permanence space in the de Gröer plan is the lowest of the nine analysed plans. This is because during twentieth century, primacy was given to mobility within the public space therefore, justifying its 66% occupancy of the street area.

From Table 1 it is possible to observe that only Plan 4 was able to control the overall space. The lack of residual voids in this plan justifies this situation.

Plans 1, 2, 3, 4, the Chosen plan, and the Tinoco plan all present an identical proportion of street area and permanence area. Therefore, Plan 4 should be highlighted due to the fact that its specific area of public space occupies 50% of the plan.

Still, regarding public space, one should also call attention to the similarities of the street area among Plan 6, the Present-day plan, and the de Gröer plan. When compared with the Present-day plan, the de Gröer plan proposes a new street structure (running north-south) that greatly approximates the north-south street arrangements seen in Plan 6. Both de Gröer and Plan 6 present 10 streets (north-south) in the central area of the plan.

While evaluating the permanence areas of the different plans, it is possible to observe that the plans that present the lowest area of *largos* and *adros* are also those plans which present the lowest number of churches. These are the Chosen plan, the Present-day plan and the de Gröer plan.

From the analysis of the built area in Plan 3, it is possible to verify, at the ground level, that a great uniformity exists in the use of distribution in all the plans, which included places seen in the 1756 competition, in the Chosen plan, and in the plan that anticipated the earthquake (Tinoco's plan). Considering that the principal uses for these buildings was residential, as requested by the competition, one can assume that the residential area varies between 73% and 84%, and that the area occupied by notable buildings would oscillate between 16% and 27%. The Present-day plan and the de Gröer plan present the lowest areas occupied by notable buildings (15% in the Present-day plan and 9% in the de Gröer plan). Instead, notable buildings present the highest areas in other uses (this includes commerce and services that have successively substituted the former residential uses), 85% and 91% in the Present-day plan and the de Gröer plan, respectively.

From the comparative analysis analysing the differences between the two mains squares (Terreiro do Paço and Rossio) it is possible to verify that Terreiro do Paço square occupies a larger square area than the Rossio square. That should be justified by the successive high hierarchical uses acquired by the Terreiro do Paço square throughout history. It is interesting to note the ratio between these two squares in Plan 3, wherein Terreiro do Paço square is 3,3 times larger than Rossio square.

From this comparative analysis, it is also possible to verify that the two main squares maintain their proportion in Plan 2 and the Tinoco plan. In both those plans, Terreiro do Paço square is 2.2 times larger than Rossio square. Similar results can be seen in Plan 6 and in the Chosen plan, where Terreiro do Paço square is 1.7 times larger than Rossio square.

When one compares the dimensions of the two main squares, Terreiro do Paço and Rossio, for each plan and for the Present-day plan, one can conclude that the Chosen plan is the one that most closely represents the closest dimensional areas of the Present-day plan (99% when comparing the Rossio squares and 105% when comparing the Terreiro do Paço squares)

When one compares the dimensions of the two main squares, Terreiro do Paço and Rossio in relation to Plan 2, the Tinoco Plan, and the Present-day plan, one can verify an identical proportion among all three plans. Indeed, in Plan 2, Rossio square occupies 84% of the plan and Terreiro do Paço occupies 117%. The respective percentages for the Tinoco plan are 82% for Rossio and 114% for Terreiro do Paço.

5 Conclusions

This work evaluated the public space in nine plans for downtown Lisbon spanning several hundred years. The Tinoco Plan was the oldest plan, having been developed during the Renaissance. Six other plans refer to the proposals presented at the 1756-58 competition for the reconstruction of Lisbon in the aftermath of the 1755 earthquake (Plans 1, 2, 3, 4, and 6, and the Chosen plan). Two other plans were analysed and evaluated as well. These are the plan by the architect Étienne de Gröer, from the mid-twentieth century, created for the reformulation of downtown Lisbon, and the Present-day plan that represents the plans for Lisbon in the twenty-first century.

The analysis followed a methodology for the quantification of the public spaces and the built areas presented in each plan. Secondly, the results were evaluated against the urban design of each plan and information relative to the history of each plan was applied to the analysis. The main elements analysed in this study coincide with those used by Conzen in similar studies.

The present methodology of public space evaluation might be useful for future applications in several ways: either for the evaluation of urban proposals, or for the redefinition of existing urban spaces. Nevertheless further comparisons with other evaluation models or urban spaces would benefit the proposed methodology.

From a historical and chronological analyses, this investigation has made it possible to verify of the following: The Renaissance plan presents an urban design proposal based on public space ratio of 27%; The Enlightenment period plans present urban design proposals with a public space ratio that varies between 37% and 46%; finally, the twentieth and twenty-first century plans present a public space ratio of 47% and 50%, respectively.

The comparative quantification of the public space evaluation has allowed us to verify the existence of a great uniformity in the public space areas among all the nine plans analysed. The reason for this rests on the fact that the urban morphology of the nine plans is practically identical. Nevertheless, that same amount of public space areas could be found in an urban design proposal with a distinct urban morphological approach.

From the various plans proposed for the Baixa competition, Plan 6 stands out as offering the highest public space ratio (46%). This is justified by its urban design, which presents the widest streets of all the proposals. Interestingly, the de Gröer Plan, when compared to the Present-day plan, proposes a new street structure (running north-south) that greatly approximates the north-south street urban arrangements presented in Plan 6.

As can be seen throughout all the plans, although Lisbon's main squares, Terreiro do Paço and Rossio, have remained formally distinct, they have maintained approximately the same areas throughout history.

From the area distribution of the different plans studied one can observe that every plan is similar in some ways to all the other plans. This is reflected in the similar power law exponents that were found for the block area distribution in Table 1. The same type of behaviours could not be generalized for other features, such as churches or *largos* and *adros*; however, in some plans power law behaviour was visible, as shown in fig. 2 and 3. This power law behaviour provides evidence that city size features are dependent on each other in a quantifiable and predictable way. This information also complements the analysis results of the urban features shown in Tables 2, 3, and 4 because it demonstrates how a certain percentage of a feature is actually distributed. For example, in the Tinoco plan, the 62% block area is distributed in a power law manner up to approximately rank 30 and then the block size starts declining quickly in an exponential manner. This analysis is then helpful in understanding the broad range of areas associated with each element of the urban fabric.

Based on this evaluation, and supported by quantitative and qualitative parameters of reference (for example, Krier's [1999] theory of the 'good proportion of public space'), one could now redraw each plan. This would be accomplished with the aim of achieving a good proportion of public space and built area. In order to do so, it would just be necessary to add or subtract certain elements.

Therefore, this methodology is useful because it allows a better understanding of the city. It helps the urban planner design new areas of the city (or redesign old ones). It also helps policymakers choose between different alternative plans according to public priorities. Further, it helps the city's citizens understand how certain features of the spaces in which they live are related in certain ways.

Appendices

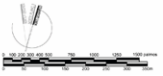
Vector format showing built areas.

Vector format showing public space

Source (according Portuguese cataloguing norm NP-405-2)

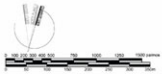
1. Cidade antes do Terramoto (Tinoco) [Carta topographica da parte//mais arruinada de Lisboa na//forma, em que se achava antes//da sua destruição para sobre ella//se observarem os melhora//mentos necessários//Reducção à escala 1:2500 da planta//que desapareceu no Archivo do Comando//Geral de Engenharia] [Material cartográfico]

AUTHOR(S): SILVA, Augusto Vieira da
SCALE: Duas escalas gráficas: uma Esc. gráf. de 100 Varas e outra em metros 1/2500
PUBLICATION: [s.l.]: [s.n.], 1898
PHYSICAL DESCRIPTION: 1 map.; ms. a vermelho s. tela; 49x39 cm
NOTES: Planta de Lisboa anterior ao terramoto de 1755 redesenhada em 1898 pelo olissipógrafo Augusto Vieira da Silva.
REFERENCE (Archive/Library): MC.DES.1479
ARCHIVE : Museu da Cidade



2. Plano nº 1
[Planta nº 1//Plano da cidade de Lisboa baixa destruída em que vão// sinaladas por linhas de pontinhos de tinta preta as Ruas// traveças, e becos antigos, e sobre o mesmo plano se mostrão// em branco as Ruas melhoradas assim as largas, como as es//treitas de mayor uso, como também sobre os becos, e Ruas me//nores se desenhão novas ruas que se poderão ou escuzar,// ou abraçar ficando os lugares que os edifícios occupão la//vados de aguada preta; As Igrejas dos Conventos, Freguesias e Ermidas vão sinaladas com água de Carmim,// e a divizão das Freguesia de cor azul.] [Material cartográfico]

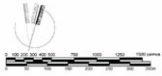
AUTHOR(S): [FONSECA, Pedro Gualter da; CUNHA, Francisco Pinheiro da]
SCALE: Esc. gráf. de 600 Palmos
PUBLICATION: Séc. XVIII (2ª metade)
PHYSICAL DESCRIPTION: Tinta-da-china e aguarela s/ papel; 64,5 x 85,5 cm
NOTES: Exposição permanente do Museu da Cidade
REFERENCE (Archive/Library): MC.DES .975
ARCHIVE : Museu da Cidade



3. Plano nº 2

[Planta nº 2// Planta da Cidade de Lisboa baixa arruinada// em que vão de linhas pretas delgadas as ru//as e travessas antigas, e em branco as ruas de no//vo escolhidas, os edifícios novos de carmim claro, // as Igrejas com carmim mais forte, e a cruz, e a // divisão das freguezias de azul.] [Material cartográfico]

AUTHOR(S): [POPPE, Elias Sebastião; POPPE, José Domingos]
SCALE: Esc. gráf. de 1000 Palmos
PUBLICATION: Séc. XVIII (2ª metade)
PHYSICAL DESCRIPTION: Tinta-da-china e aguarela s/ papel; 64,5 x 86,5 cm
NOTES: Exposição permanente do Museu da Cidade
REFERENCE (Archive/Library): MC.DES. 976
ARCHIVE : Museu da Cidade



4. Plano nº 3

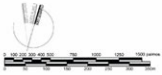
[Planta nº 3 // Plano da Cidade de Lisboa baixa des//truída, em que vão signaladas com punctu//ação preta todas as ruas, travessas e becos // antigos, e as ruas novamente escolhidas, e // formadas com toda a liberdade se mostrão // em branco, e os sitios dos edifícios novos de // amarello, e as Igrejas e lugares que se con//servão sem mudança de carmim forte, e a // Alfandega do tabaco, Baluarte do terreyro do // Paço e sua cortina, que se devem derribar pa//ra restar formado o grande terreyro do Paço – //vão lavados de huma agoada de carmim, como // também algumas porções de edifícios do arco // do açougue té á entrada do Pelourinho, que tão // bem se hão de derribar para complemento do // mesmo terreyro do Paço com semelhante agoada // e a divizão das freg as com cor azul.] [Material cartográfico]

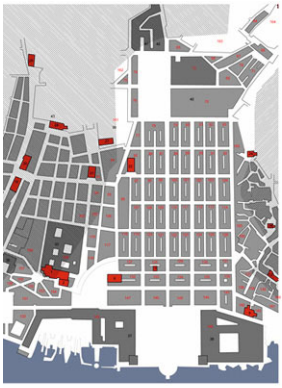
AUTHOR(S): [CARVALHO, Eugénio dos Santos; ANDREIAS, António Carlos]
SCALE: Esc. gráf. de 1000 Palmos
PUBLICATION: Séc. XVIII (2ª metade)
PHYSICAL DESCRIPTION: Tinta-da-china e aguarela s/ papel; 64 x110 cm
NOTES: -
REFERENCE (Archive/Library): MC.DES.1782
ARCHIVE : Museu da Cidade

5. Plano nº 4

[Planta nº 4 // Formada ainda com mais // liberdade sem attender a // conservar as Igrejas nos se//us próprios sítios, nem ou//tro algum edifício, como bem // se descobre na delineação do // antigo muyto mais fino.] [Material cartográfico]

AUTHOR(S): [FONSECA, Pedro Gualter]
SCALE: Esc. gráf. de 140 Varas
PUBLICATION: Séc. XVIII (2ª metade)
PHYSICAL DESCRIPTION: Tinta-da-china e aguarela s/ papel; 64 X 84 cm
NOTES: Exposição permanente do Museu da Cidade
REFERENCE (Archive/Library): MC.DES.978
ARCHIVE : Museu da Cidade





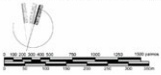
6. Plano Escolhido

[Planta topográfica da cidade de Lisboa arruinada também segundo o novo alinhamento dos architectos Eugénio dos Santos Carvalho e Carlos Mardel] [Material cartográfico]

AUTHOR(S): RIBEIRO, João Pedro
SCALE: Esc. gráf. de 2000 Palmos
PUBLICATION: 1947
PHYSICAL DESCRIPTION: Litografia colorida; 5,7cm X 8,3cm
NOTES: Exposição permanente do Museu da Cidade
REFERENCE (Archive/Library): MC.GRA.35
ARCHIVE : Museu da Cidade

[Planta topográfica da Cidade de Lisboa arruinada, // e também segundo o novo Alinhamento dos Architéctos// Eugénio dos Santos Carvalho, e Carlos Mardel] [Material cartográfico]

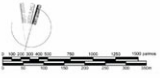
AUTHOR(S): SILVA, Augusto Vieira da
SCALE: Esc. gráf. de 2000 Palmos
PUBLICATION: Setembro de 1899
PHYSICAL DESCRIPTION: Desenho a tinta da china, aguarelado a rosa e amarelo; 118,9 cm x76,4 cm
NOTES: -
REFERENCE (Archive/Library): -
ARCHIVE : Museu da Cidade



7. Plano nº 6

[Planta // para a renovação // da cidade de Lisboa // baixa destruída ide//ada com toda a li//berdade, assim dê//tro da povoação, co//rno na marinha sê // atender a conserva//ção de couza alguma // antiga, assim sagra//da, como profana.] [Material cartográfico]

AUTHOR(S): [POPPE, Elias Sebastião]
SCALE: -
PUBLICATION: Séc. XVIII (2ª metade)
PHYSICAL DESCRIPTION: Tinta-da-china e aguarela s/papel; 65 X 87 cm
NOTES: -
REFERENCE (Archive/Library): MC.DES.0980
ARCHIVE : Museu da Cidade



8a 8b. Plano do Arquitecto De Groer

[Plano Director de Lisboa, Estudo Pormenorizado da Transformação da Baixa. Saneamento dos Quarteirões e Melhoramento da Circulação] [Material cartográfico]

AUTHOR(S): Etienne De Groer
SCALE: -
PUBLICATION: 27.09.1948
PHYSICAL DESCRIPTION: esquissos, dim : 400 larg. x 500 alt., lápis de cor sobre papel colado em cartão
NOTES: in TOSTÕES, A. & ROSSA, W. (2009) Lisboa 1758 : O plano da baixa hoje. IN CML (Ed.) ROSSA, Walter ed. Lisboa, Câmara Municipal de Lisboa, Pelouro de Urbanismo e Reabilitação Urbana e o Pelouro de Cultura, Educação e Juventude.
REFERENCE (Archive/Library): -
ARCHIVE : Colecção Particular

[Plano Director de Lisboa (detalhe)] [Material cartográfico]

AUTHOR(S): Etienne De Groer
SCALE: -
PUBLICATION: 1948
PHYSICAL DESCRIPTION: esquissos, dim : 42 larg. x 32,5 alt., lápis de cor sobre papel colado em cartão
NOTES: in TOSTÕES, A. & ROSSA, W. (2009) Lisboa 1758 : O plano da baixa hoje. IN CML (Ed.) ROSSA, Walter ed. Lisboa, Câmara Municipal de Lisboa, Pelouro de Urbanismo e Reabilitação Urbana e o Pelouro de Cultura, Educação e Juventude.
REFERENCE (Archive/Library): -
ARCHIVE : -

9. Actual

Cartografia Actual da CML

Acknowledgments

We would like to thank architect Sandra Gerardo for the work done in the preparation of some of the materials contained in this paper and for vectoring the base plans for analysis.

Notes

1. The fact that the Chosen plan is missing is known to almost all the researchers that have studied the post-earthquake Lisbon [Sampayo and Rodrigues 2009]. A recent investigation regarding this meter [M. Santos 2009] has contributed with a new theory, in which the known Plan 6 is considered to be the missing Plan 5.
2. Concepts within the permanence spaces, according to international glossaries of urban form, are generally designated as squares. However, in the Portuguese language, these spaces present

different meanings. It is important to stress this issue because some of these spaces affect changes in their designation, in different periods of time, when specific characteristics also change. For example the pre-earthquake Largo dos Remolare was renamed Praça dos Remulares after the earthquake and is known today as Praça Duque da Terceira. Regarding concepts of urban form in Portuguese literature see also [Dias 2000] and [Tudela 1997].

3. However, there are researchers that refer to the concept of square for other periods in history. For example, Françoise Choay refers to the square in the Middle Ages [Choay and Merlin 1988].
4. Besides the archives of "Gabinete de Estudos Arqueológicos da Engenharia Militar"(GEAEM) and of the City Museum, other archives were also investigated for the work presented in this paper. These were the archives of "Gabinete de Estudos Olisiponenses" (GEO) and the digital archive of urban cartography (CEURBAN).

References

BATTY, M. 2007. *Cities and Complexity: Understanding Cities with Cellular Automata, Agent-Based Models, and Fractals*. Cambridge, MA: MIT Press.

BENEDIKT, M. L. 1979. To take hold of space: isovists and isovist fields. *Environment and Planning B: Planning and Design* **6**: 47-65.

BLANCHARD, P. and D. VOLCHENKOV. 2008a. Exploring Urban Environments By Random Walks. In vol. 1021, pp. 183-203 of *Stochastic and Quantum Dynamics of Biomolecular Systems: Proceedings of the 5th Jagna International Workshop*. DOI 10.1063/1.2956796.

———. 2008b. *Mathematical Analysis of Urban Spatial Networks*. Berlin, Heidelberg: Springer.

CARMONA, M., S. TIESDELL, T. HEATH and T. OC. 2010. *Public Places – Urban Spaces: The Dimensions of Urban Design*. 2nd ed. Oxford: Architectural Press.

CASTEX, J., J. C. DEPAULE. and P. PANERAI. 1977. *Formes urbaines: de l'ilot a la barre*. Paris: Dunod.

CASTEX, J. and PANERAI, P. 1971. Notes sur la structure de l'espace urbain. *Architecture d'Aujourd'hui* **153**: 30-33.

CHOAY, F. and MERLIN, P. 1988. *Dictionnaire de l'urbanisme et de l'aménagement*. Paris: Presses Universitaires de France.

CONZEN, M. R. G. 1960. *Alnwick, Northumberland: A study in town plan analysis*. London: Institute of British Geographers.

DIAS, F. D. S. 2000. Tipologia de espaços urbanos: análise toponímica. Pp. 301-310 in *III Jornadas sobre toponímia de Lisboa*, António Trindade, Paula Machado, Teresa Sancha Pereira, coord. Lisbon: CM.

EULER, L. 1741. Solvtio Problematis Ad Geometriam Sitvs Pertinentis (E53). *Commentarii academiae scientiarum Petropolitanae* **8**: 128-140. Rpt. *Leonhard Euler Opera Omnia*, series 1, vol. 7, pp. 1-10.

FRANÇA, J.-A. 1987. *Lisboa Pombalina e o Iluminismo*. Lisbon: Bertrand Editora.

HEITOR, T. K. M., J. MUCHAGATO, and A. TOSTÕES. 1999. Breaking of the medieval space. The Emergence of a New City of Enlightenment. In: *Second International Space Syntax Symposium*, vol. II. Brasilia.

HILLIER, B. and HANSON, J. 1989. *The Social Logic of Space*. Cambridge: Cambridge University Press.

KRIER, L. 1978. Fourth Lesson: Analysis and project of traditional urban block. *Lotus International* **19** (*L'isolato urbano / The urban block*): 42-54.

———. 1979. Communities versus zones: A plan for Sodermalm in Stockholm. *Lotus International* **36**: 22-24.

———. 1999. *Arquitectura : escolha ou fatalidade*. Lisbon: Estar Editora.

KRIER, R. 1979. Typological and Morphological elements of the concept of urban space. *Architectural Design* **49**: 1-17.

KROPF, K. 1998. Facing up to evolution. *Urban Morphology* **2**: 45-47.

KRÜGER, M. 1998. *A Sintaxe da Cidade de Lisboa. Contribuições Para o Desenvolvimento da Cidade*. Coimbra: FCTUC.

LOPES DOS SANTOS, V. M. V. 1994. O sistema construtivo pombalino em Lisboa em edifícios urbanos agrupados de habitação colectiva. Estudo de um legado humanista da segunda metade do Século XVIII. Contributos para uma abordagem na área da recuperação e restauro arquitectónico do património construído. Ph.D. thesis, Universidade Técnica de Lisboa.

LYNCH, K. 1981. *A Theory of Good City Form*. Cambridge, MA: MIT Press.

———. 1996. *The Image of the City*. Cambridge, MA: MIT Press.

MARAT-MENDES, T. 2002. The Sustainable Urban Form: A comparative study in Lisbon, Edinburgh and Barcelona. Ph.D. thesis, University of Nottingham.

MILLER, J. G. 1978. *Living systems*. Niwot, CO: University of Colorado Press.

MONTEIRO, C. 2010. *Escrever Direito por linhas rectas: Legislação e planeamento urbanístico na Baixa de Lisboa (1755-1833)*. Lisbon: AAFDL.

MOREIRA, M. P. P. C. 1993. Conservation of an historic urban centre a study of downtown pombaline Lisbon. Ph.D. thesis, Institute of Advanced Architectural Studies, University of York.

MORRIS, A. E. J. 1994. *History of Urban Form before the Industrial Revolution*. Essex: Longman.

MOUDON, A. V. 1986. *Built for Change. Neighbourhood Architecture in San Francisco*. Cambridge, MA: MIT Press.

———. 1997. Urban Morphology as an emerging interdisciplinary field. *Urban Morphology* 1: 3-10.

MULLIN, J. R. 1992. The reconstruction of Lisbon following the earthquake of 1755: a study of despotic planning. *Planning Perspectives* **7**, 7: 157-179.

MURATORI, S. 1959. *Studi per una operante stiria urbana di Venezia*. Rome: Instituto Poligraphico dello Stato.

PAPAGEORGIOU, A. 1971. *Continuity and Change. Preservation in City Planning*. London: Pall Mall Press.

PEREIRA, L. V. 1983. *A forma urbana no planeamento físico*. Lisbon: Laboratório Nacional de Engenharia Civil.

RAPOPORT, A. 1990. *History and Precedents in Environmental Design*. New York: Plenum.

ROSSI, A. 1983. *The Architecture of the City*. Cambridge, MA: MIT Press.

SAMPAYO, M. and RODRIGUES, D. 2009. The Five Plans for the Aftermath of 1755 Lisbon Earthquake: The Interplay of Urban Public Spaces. ISUF Conference 2009 "Urban morphology and urban transformation". Guangzhou, China.

SAMPAYO, M. G. T. D. 2007. Theoretical fundamentals in the construction of the portuguese public squares of the 18th Century. In: ISUF (ed.) Fourteenth International Seminar on Urban Form. Ouro Preto, Minas Gerais, Brazil.

SAMUELS, I. 1993. Working in the park: changes in the form of employment locations. Pp. 113-121 in *Making Better Places: Urban Design Now*, R. Hayward and S. McGlynn, eds. Oxford: Butterwoth Architecture.

SAMUELS, I. 1997. From description to prescription: reflections on the use of a morphological approach in urban design guidance. *Urban Design International* **2**: 81-91.

———. 1999. A typomorphological approach to design: the plan for St Gervais. *Urban Design International* 4: 129-141.

SANTOS, M. H. R. D. 2009. Os seis planos da reconstrução. In: *Jornadas sobre A CIDADE POMBALINA: História, Urbanismo e Arquitectura Os 250 Anos do Plano da Baixa, 2008 Lisboa*. Lisbon: Grupo 'Amigos de Lisboa' and Fundação das Casas de Fronteira e Alorna.

SAVAGE, V. and G. WEST. 2006. Biological Scaling and Physiological Time. Biomedical Applications. Pp. 141-164 in *Complex Systems Science in Biomedicine*, T. Deisboeck and J. Yasha Kresh, eds. Heidelberg: Springer.

SIKSNA, A. 1990. A comparative study of Block size and form (in selected New Towns in the history of western civilisation and in selected North American and Australian City Centres). Ph.D. thesis, The University of Queensland.

SOLÁ-MORALES, M. de. 1978. Towards a Definition. *Lotus International* **19** (*L'isolato urbano / The urban block*): 28-36.

TOSTÕES, A. and W. ROSSA, eds. 2008. Lisboa 1758 : O plano da baixa hoje. Exhibition catalogue. (Eng. trans. *Lisboa 1758 - The Baixa Plan Today*). Lisbon: Câmara Municipal de Lisboa.

TUDELA, J. 1977. *As praças e largos de Lisboa: esboço para uma sistematização caracterológica*. Lisbon: Câmara Municipal Lisboa.
WHITEHAND, J. 1981. *The urban landscape: Historical Development and Management. Papers by M. R. G. Conzen*. London: Academic Press.
———. 1990. Townscape management: ideal and reality. Pp. 147-158 in *The Built form of Western Cities. Essays for M.G. Conzen on the occasion of his eightieth birthday*, T. R. Slater, ed. London: Leicester University Press.
———. 2000. From explanation to prescription. *Urban Morphology* **4**: 1-2.
———. 2001. British urban morphology: the Conzenian tradition. *Urban Morphology* **5**: 103-109.
ZIPF, G. K. 1949. *Human behavior and the principle of least effort*. Cambridge, MA: Addison-Wesley Press.

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