ICEUBI2015 University of Beira Interior
December 2 3 4 International Conference on Engineering
Engineering for Society

Random-walk connectivity of Lisbon's waterfront in the post-1755 reconstruction

Mafalda Sampayo - mgts@iscte.pt
ISCTE-IUL
David Sousa-Rodrigues - david@davidrodrigues.org
The Open University, UK

Abstract
In this paper the post-1755 Lisbon connectivity of the city of Lisbon with the river Tagus is analysed with a random-walk agent-based simulation. This approach takes advantage of the simulation power of modern computation and the results highlight aspects of potential micro-dynamics of cities that would be invisible to analysis otherwise. The plans drawn for the city of Lisbon meant a departure from the medieval model of city in terms of mobility. The intricacy of the old city circulation spaces was greatly reduced in the new plans and connections between different areas were substantially improved. The results from the simulation of the random walk model, showed that the plans that kept the main force lines of the old city (plans 1,2 and 3) were the ones that had the less improvement in terms of mobility in respect to the random-walk model. The plans that had greater freedom from Manuel da Maya (plans 4, 6 and the chosen one) are, by contrast, easier to navigate. The chosen plan presents the highest permeability and connectivity of all the urban fabric of the several post-1755 plans and higher also that the late medieval city.

Resumo
Neste artigo é calculada a conectividade da cidade de Lisboa pós 1755 com o rio Tejo através de uma simulação de agentes com caminhadas aleatórias. Este procedimento tem como vantagem o aproveitamento do poder explicativo da simulação potenciado pela capacidade computacional atual. Os resultados mostram aspectos das micro-dinâmicas das cidades que são invisíveis em outras análises. Os planos desenhados para a reconstrução da cidade de Lisboa significam uma mudança em relação ao modelo de cidade medieval em termos de mobilidade urbana. A tortuosidade dos espaços de circulação da antiga cidade é reduzida nos novos planos e as ligações entre as diversas zonas é melhorada substancialmente. Os resultados da simulação do modelo de caminhada aleatória mostram que os planos que mantiveram as linhas de força das pré-existências (planos 1,2 e 3) são aqueles que apresentam menos melhorias em termos de potencial de mobilidade. Os planos em que Manuel da Maya deu mais liberdade de concepção (planos 4, 6 e escolhido) são, por contraste, de navegação mais fácil. O plano escolhido é o que apresenta um tecido urbano mais permeável e conectado com a frente ribeirinha de todas as propostas pós-1755 e também em relação à cidade tardo-medieval.

Keywords
Lisbon, random-walks, urban form, agent-based simulation, waterfronts

Palavras-chave
Lisboa, caminhadas aleatórias, forma urbana, simulação de agentes, frentes ribeirinhas

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Introduction

Through out history the relation of cities with their rivers has not always been the same. In several cities with waterfronts the parallel and perpendicular disposition of streets in relation to the waterfront is evident. It has been justified from an economical perspective (allowing for a stronger connectivity with the river), for aesthetic reasons and also due to scientific reasons. Cristovão Ayres makes the rhetorical question about the seismic considerations taken into account in the development of the city by evoking Kant's advice:

> *Is it possible that the great Marquis of Pombal, at the time when he was planning the new Lisbon, noticed the important advice from the illustrious philosopher: that the arteries of the great threatened cities shouldn't be built parallel to water lines (in the case of Lisbon from West to East), because the movement of the shake follows that same direction and prolongs itself through the riverbank?* [1]
>
> "*Teria o grande Marquês de Pombal, na epoca em que delineava o novo plano de Lisboa, noticia do seguinte importante conselho do illustre philosopho: que as arterias das grandes cidades ameaçadas não se devem construir paralelas ás vias fluviaes (isto é, emquanto a Lisboa, do Occidente para o Oriente), porque o movimento do tremor segue essa direcção e prolonga-se pelo curso dos rios?*" in the original [1].

The urban design adopted by the Portuguese military engineers in Lisbon can be explained in the light of the seismology knowledge available at the time to them. This knowledge is evidenced by the existence of a copy of the book "História Universal dos Terramotos" (Universal History of Earthquakes) by Joaquim José Moreira da Mendonça in the private library of Eugénio dos Santos [2].

More or less connected with the river, the city of Lisbon was in essence a waterfront city until the mid-XIX century. It is natural then to see represented its political, religious, and economical powers through buildings and symbolic spaces.

The study of the city can be made at different levels and using different tools and a usual representation of the public space is in the form of graphs [3]. Graph theory, had its first application in an urban context: Euler solved the problem of the Königsberg bridges in 1735 using graph theory [4]. During the 1980-1990s, Space Syntax has taken a new revitalized approach of graph theory to measuring city features [5]. Recently agent-based simulation has gained particular interest, as some non-linear features are not possible to account with traditional reductionist approaches [6]. The non-linearity of social aspects of life systems is also manifested in cities and the mathematical analysis of urban spatial networks as been given a particular attention with the work on random walks in urban contexts by Blanchard and Volchenkov [7].

In Lisbon, the post-earthquake plans for the downtown are, at first sight, highly connected with the river (when compared to the pre-1755 city). The quantification of the public spaces of these plans revealed different philosophical approaches to urban design as shown by Sampayo and Sousa-Rodrigues [8,9] and by Marat-Mendes, Sampayo and Sousa-Rodrigues [10]. The work of Kruger [11] and Heitor, Muchagato and Tostões [12] on the other hand show a different view of this connectivity, as it has been analysed under the space syntax framework where the boundary imposed by the river creates a bias in the results towards central graph nodes.

In this paper the post-1755 Lisbon connectivity of the city of Lisbon with the river Tagus is analysed with a random-walk agent-based simulation. This approach takes advantage of the simulation power of modern computation and the results highlight aspects of potential micro-dynamics of cities that would be invisible to analysis otherwise.

Methods

Archival Research

The archival research revealed the existence of several copies of the same plans with small subtle differences between them [13]. In the "Gabinete de Estudos Arqueológicos da Engenharia Militar"(GEAEM) four plans were found (although França had identified five during the '60s, meaning that one has been missing since then [14]): Plan 1, Plan 2, Plan 4 and Plan 6. In the City's Museum the following plans were identified: Plan 1, Plan 2, Plan 3 (two identical versions), Plan 4, Plan 6 and also a plan of downtown before the earthquake.

Plan 5 is still missing and could not be found. Also there is no registration of which of the existing copies/plans were used in the third part of Manuel da Maya dissertation. The fact that plan 5 is missing is known to almost all the researchers that studied the post-earthquake Lisbon. This was also noticed by Santos [15]. On the other hand, the duplicity of some of the other plans (e.g. plan 3) went unnoticed through many years [13].

Because of the small differences between the plans found in the two archives, in this work the plans in the City Museum were used. The plans were digitized and rescaled to allow the comparison of features between the five plans (1, 2, 3, 4 and 6). When superimposing the five plans, small misplacements of common buildings are observed, mainly in the Plan 2. This is possibly due to the different precision of the drawings at that time (when compared to modern age) and this is even stated by Manuel da Maya when he advised that during the reconstruction, the plan and the place had to come together, reconciled.

Random-Walk Model description

The connectivity between the two main squares of the city (Rossio and Terreiro do Paço) — and consequently the connectivity of the city with its waterfront — was studied with the help a computer agent-based simulation. To study the plans produced after 1755 the plans were digitised and an agent-based simulation was implemented in Netlogo. Agents would traverse the raster images obtained from the digitisation of each plan of the city and their movement acts as a proxy for the intricacy of the streets between the two main squares. This agent-based simulation implemented a random-walk model of the pedestrian population. The basic idea behind this process is to use a stochastic random-walk process to identify the structure of the circulation between the two zones.

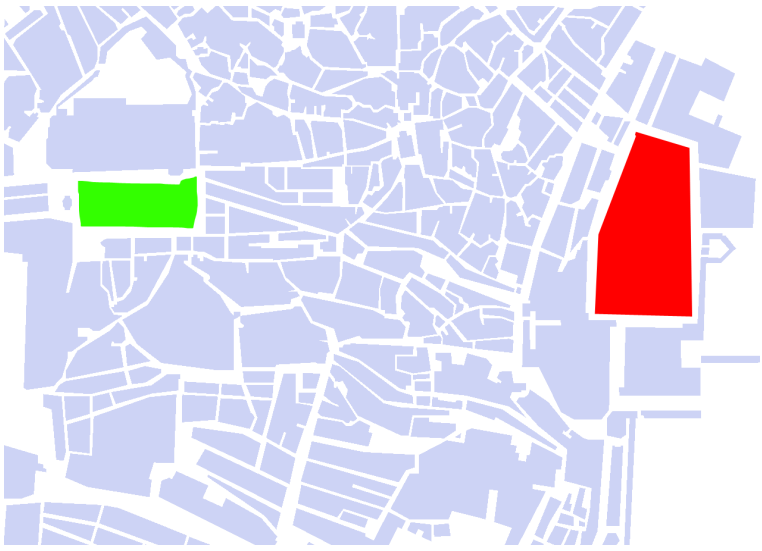

Figure 1 – Plan of the city of Lisbon before the 1755 earthquake, showing the departure zone in green and the arrival zone in red.

The several plans of the city were prepared with two defining painted zones. This two zones mark the departure (green) and destiny (red) zones (Figure 1). This zones were drawn in the Rossio (green) and Terreiro do Paço (red) squares, and the average distance of runs from one to the other gives a measure of the intricacy of the urban fabric in between and it is a measure of potential population mobility. In the simulation, a pedestrian agent follows a random walk sub-model. The sub-model for the description of the pedestrian random-walk measure is given by the following rules:

- agents follow a straight line until it hits an obstacle;
- when hitting an obstacle, agents invert direction choosing a new direction randomly.

This stochastic process has similarities to that of a gas inside a container, where molecules move freely in a straight line until they bounce of the walls or other molecules and in this way filling the entire volume over time. When applied to the plans, and noting that agents are being removed at the destiny zone and that they are re-spawn at the departure zone, it is possible to calculate the average time / distance an agent takes to go from one zone to the other. This measurement will give a quantitative idea of how constrained the circulation spaces design is for a random-walk agent. Naturally this kind of agent is different from a rational human agent, making decisions about where to go and where to turn, but he measure is indicative of the permeability and navigability of the circulation spaces' patterns.

The simulation is starts with number of agents (250) in the green zone (Rossio), each with a random heading. At each step each agent moves according to the pedestrian stochastic random walk sub-model. The distances walked are tracked and the simulation is stopped when the average time taken to travel between the two zones stabilizes at steady state value. For consistency the simulation is ran further until there are at least 10000 agent runs between Rossio and Terreiro do Paço.

Results

Connectivity between the main squares

The results of the connectivity between the two main squares of the Lisbon plans (Rossio and Terreiro do Paço) were obtained via simulation based in the model described. An average distance was calculated for the random walk of 10000 agents that traverse from Rossio to Terreiro do Paço. The results were normalised considering the pre-1755 Lisbon as the base (index 100). The comparison of the other plants is shown in Table 1.

Table 1 – Average distance index (base 100 = Pre-1755) of the connectivity analysis between Rossio and Terreiro do Paço via the random-walks of agent-based simulation

	Av. Distance Index
Pre-1755	100
Plan 1	25
Plan 2	22
Plan 3	21
Plan 4	10
Plan 5	-
Plan 6	15
Chosen	10

In Table 1 plan 5 couldn't be simulated, as the plan is missing. It is observable that all plans show a significant reduction in the average distance of travelling from Rossio to Terreiro do Paço by the random-walk agents. It is also noticeable a difference between the two sets of plans. Plan 1,2 and 3, that were constrained by the pre-existences, show a higher value for the average distance than the values for the latter plans (4,6 and chosen).

Conclusion

This paper showed how the different options for the reconstruction of the city of Lisbon would have impacted the city being rebuilt in terms of the impact of the connectivity of the circulation spaces.

The plans drawn for the city of Lisbon meant a departure from the medieval model of city in terms of mobility. The intricacy of the old city circulation spaces was greatly reduced in the new plans and connections between different areas were substantially improved. The results from the simulation of the random walk model, showed that the plans that kept the main force lines of the old city (plans 1,2 and 3) were the ones that had the less improvement in terms of mobility in respect to the random-walk model. The plans that had greater freedom from Manuel da Maya (plans 4, 6 and the chosen one) are, by contrast, easier to navigate. The chosen plan presented a 10 times effect on the distances between the two main squares of the city, making this connection highly effective.

In the end Lisbon reconstruction followed a plan that included a shift in the traditional notions of mobility that affected the daily lives of its citizens by potentiating an easy access to the waterfront, simplifying orientation and navigability

The chosen plan was, and still is, a success from the urban point of view. Its success is so evident that de Groer words resonate today in our minds. The XVIII century plan is the "dorsal spine" of the Portuguese capital:

> *"Les artères du plan, établi à ce moment, forment jusqu'à présent l'ossature de la capitale portugaise et lui impriment son individualité."* [16].

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