

Mafalda Teixeira de Sampayo\* and David Sousa-Rodrigues

# Random-walk mobility analysis of Lisbon's plans for the post-1755 reconstruction

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**Abstract:** The different options for the reconstruction of the city of Lisbon in the aftermath of the 1755 earthquake are studied with an agent-based model based on random-walks. This method gives a comparative quantitative measure of mobility of the circulation spaces within the city. The plans proposed for the city of Lisbon signified a departure from the medieval mobility city model. The intricacy of the old city circulation spaces is greatly reduced in the new plans and the mobility between different areas is substantially improved. The simulation results of the random-walk model show that those plans keeping the main force lines of the old city presented less improvement in terms of mobility. The plans that had greater design freedom were, by contrast, easier to navigate. Lisbon's reconstruction followed a plan that included a shift in the traditional notions of mobility. This affected the daily lives of its citizens by potentiating an easy access to the waterfront, simplifying orientation and navigability. Using the random-walk model it is shown how to quantitatively measure the potential that synthetic plans have in terms of the permeability and navigability of different city public spaces.

**Keywords:** 1755 earthquake, Lisbon, urban form, waterfront, mobility, navigability, agent-based, random-walk

## 1 Introduction

The relation of cities with their rivers did not always have the same importance throughout history. In several cities the parallel and perpendicular disposition of streets in relation to its waterfront is clear. Economic perspectives (allowing for a stronger connectivity with the river), aesthetic reasons and the scientific knowledge of the time justify this layout of the city. 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 economic powers through buildings and symbolic spaces.

The study of the city can be focused at different levels using different tools and techniques. A usual representation of the public space is in the form of graphs [1–3]. Graph theory had its first application in an urban context when Euler solved the problem of the Königsberg bridges in 1735 [4]. During the 1980-1990s, following Hilier work, space syntax has taken a revitalized approach to graph theory by measuring city features [5]. Recently following the work of Batty, agent-based simulation and cellular automata have gained particular interest, as some non-linear features of cities are not possible to account using traditional reductionist approaches [6–8]. The non-linearity of social systems is naturally manifested in cities [9]. The analysis of the city of Lisbon in its different scales was studied in a recent work by Marat-Mendes and Sampayo [10]. The mathematical analysis of urban spatial networks was given particular attention in the work on random walks in urban contexts by Blanchard and Volchenkov [11–13]. This interest in the analysis of the circulation spaces is of utmost importance because the definition of the circulation spaces is the defining factor in the advance or regression of the city [14, 15].

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 [16, 17] and by Marat-Mendes, Sampayo and Sousa-Rodrigues [18]. The perma-

\*Corresponding Author: Mafalda Teixeira de Sampayo: CIES-IUL Centre for Research and Studies in Sociology, Department of Architecture and Urbanism, Lisbon University Institute, Lisbon, Portugal, E-mail: mgts@iscte.pt

David Sousa-Rodrigues: Centre for Complexity and Design, The Open University, Milton Keynes, United Kingdom, E-mail: david@davidrodrigues.org

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nence spaces of the city were studied in Sampayo and Marat-Mendes [19] where it was observed the *law of the permanence of the plan*. The work of Kruger [20] and Heitor, Muchagato and Tostões [21] shows a different view of connectivity. By using the space syntax framework, the boundary imposed by the river creates a bias in the results towards central graph nodes.

In this paper, the post-1755 Lisbon mobility of the different plans for the reconstruction of Lisbon is analysed with a random-walk [22] agent-based simulation. This approach takes advantage of the power of simulation and modern computation availability. The results highlight aspects of potential micro-dynamics of cities that would otherwise be invisible to traditional analysis.

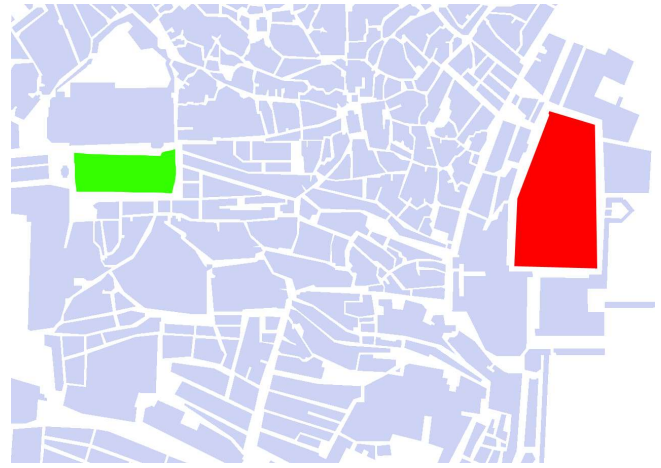
It is necessary to make a distinction between the notions of connectivity and mobility used in this paper. While *connectivity* is usually used when dealing with topological analysis – e.g. graph theory approaches like space syntax – *mobility* addresses issues of speed / time of movement between different parts of the city. Whereas *connectivity* deals with the static aspects of the layout of the city, *mobility* deals with the dynamic aspects that can happen on top of an existing connectivity [23]. *Connectivity* and *mobility* are respectively the *backcloth* and the *traffic* that characterise the relational structure of a hypernetwork representation of the urban system [9].

## 2 Methods

The archival research revealed the existence of several copies of the same plans with small subtle differences between them [24]. Of the six plans, plan 5 was missing and could not be found. Because of the small differences between the plans found in the 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 misalignments of common buildings are observed, mainly in Plan 2. Possibly, this is due to the different precisions of the drawings (when compared to modern age). This fact is even stated by Manuel da Maya when he advised that during the reconstruction, the plan and the place had to come together, reconciled [24].

The mobility between the two main squares of the city (Rossio and Terreiro do Paço) was studied with the help of a computer agent-based simulation. To study the plans produced after 1755 they 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 squares.



**Figure 1:** City of Lisbon before the 1755 earthquake, the departure zone in green and the arrival zone in red.

The several plans of the city were prepared with two defining shaded zones. These zones were drawn in Rossio (green) and Terreiro do Paço (red) squares (Figure 1). 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 for 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 they hit an obstacle;
- when hitting an obstacle, agents invert direction choosing a new direction randomly;
- when reaching the destination, agents are removed and re-spawned at the departure zone.

This stochastic process has similarities to that of a gas inside a container, where molecules move freely in a straight line until they bounce off walls, filling the entire volume over time. When applied to the plans, and noting that agents are removed at the destination zone and are re-spawned in the departure zone, the simulation allows the calculation of the average time an agent takes to travel from one zone to the other. This measure gives a quantitative idea of how constrained the circulation spaces are.

Naturally, this kind of agent is different from a rational human agent, making rational decisions about where to go and where to turn, but the measure is indicative of the permeability and navigability of the circulation spaces' patterns.

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

### 3 Results

The mobility between the two main squares of the Lisbon plans (Rossio and Terreiro do Paço) was obtained through the simulation based on the model described. The 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 (base 100 = Pre-1755) of the mobility analysis between Rossio and Terreiro do Paço.

	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

Plan 5 couldn't be simulated, as it is missing. It is observable from table 1 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, have higher values for the average distance than the values for the remaining plans (4,6 and chosen).

The plans drawn for the city of Lisbon meant a departure from the medieval mobility city model. The intricacy of the old city circulation spaces was greatly reduced in the new plans and connections between different areas were substantially improved. The simulation results of the random-walk model, showed that the plans that kept the main force lines of the old city (plans 1, 2 and 3) had the less improvement for mobility. The plans that were given greater freedom (plans 4, 6 and the chosen one) were, 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.

### 4 Conclusion

This paper showed how the different options for the reconstruction of the city of Lisbon would have affected the city being rebuilt in terms of the mobility in the circulation spaces between its two main squares, Rossio on the North limit of the city and Terreiro do Paço in the South waterfront.

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

Using the random-walk model one is able to quantitatively grasp insights about the potential that each plan had for the permeability and navigability of the different city public spaces. In presence of this work one can imagine the different cities that could have been and never were. The difference in mobility shown here are just an example of one factor in a multilevel relational system that is the city. Future work can analyse different relations and measures and come with an integrated view of the city of Lisbon.

The agent-based simulation tool showed its usefulness in studying the dynamics of mobility in the different plans. Here this was done in an historical context, but the same methodology could be applied in a public policy and urban planning context. It would be of great interest in the future to create bridges with town councils to explore these models together in the context of urban interventions.

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

The arteries of the plan, drawn up at that time, form the backbone of the Portuguese capital and imprint its individuality [25].

## References

- [1] Sousa-Rodrigues, D. – Detecção de comunidades no sistema de correio electrónico universitário [Community detection in university email systems]. *M.Sc Thesis*, Departamento de Ciências e Tecnologias de Informação – ISCTE, Lisbon, Portugal, 2009.
- [2] Sousa-Rodrigues, D. – Q-analysis based clustering of online news; Discontinuity, Nonlinearity, and Complexity, 2014, vol. 3(3), 227–236.
- [3] Johnson J. H., Jimenez-Romero C., Sousa-Rodrigues D., Bromley J. and Willis A. – Hypernetwork-based Peer Marking for Scalable Certificated Mass Education; in European Conference in Complex Systems, 2014, Lucca, Italy
- [4] Euler, Ls. – *Solvitio Problematis Ad Geometriam Sitvs Pertinentis*. *Commentarii academiae scientiarum Petropolitanae*, 1741, 8(53), 128-140.
- [5] Hilier, B., & Hanson, J. – *The Social Logic of Space: 1989*, Cambridge University Press.
- [6] Batty, M. – Agent-based pedestrian modelling. In P. A. Longley & M. Batty (Eds.), *Advanced spatial analysis: e CASA book of GIS* (pp. 81–108). Redlands: ESRI Press, 2003
- [7] Batty, M. – *Cities and Complexity: Understanding Cities with Cellular Automata, Agent-Based Models, and Fractals: 2007*, The MIT Press.
- [8] Batty, M. – *The new science of cities*. Cambridge, MA: 2013, The MIT Press.
- [9] Johnson, J. H. – The multilevel multidimensional networks of complex urban systems. CUPUM 2005 Proceedings. S. Batty. London, CASA (2005).
- [10] Marat-Mendes T, Sampayo M. – Étienne de Groër: The different scales of the urban intervention in Lisbon territory. In *Ist International Meeting EAHN (European Architectural history Network)*, Guimarães, Portugal 2010 Jun 17.
- [11] Blanchard, P., & Volchenkov, D. – Exploring Urban Environments By Random Walks, AIP Conference Proceedings, 2008, 1021, 183–203.
- [12] Blanchard, P., & Volchenkov, D. – Intelligibility and first passage times in complex urban networks. *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences*, 2008b, 464, 2153–2167.
- [13] Blanchard, P., & Volchenkov, D. – *Mathematical analysis of urban spatial networks*. Berlin: 2009, Springer.
- [14] Marat-Mendes T. – *The sustainable urban form: a comparative study in Lisbon, Edinburgh and Barcelona*, PhD Thesis, University of Nottingham, UK, 2002.
- [15] Moudon A.V. – *Built for change*. Cambridge: Massachusetts Institute of Technology. 1986.
- [16] Sampayo, M.; Sousa-Rodrigues, D. – The Five Plans for the Aftermath of 1755 Lisbon Earthquake: The Interplay of Urban Public Spaces – In the Proceedings of ISUF Conference 2009 Urban Morphology and urban transformation, 4-7 September 2009, Guangzhou, China.
- [17] Sampayo, M, Sousa-Rodrigues, D. – The Persistence of Public Space: Downtown Lisbon; in Roberto Cavallo, Susanne Kosmoss, Nicola Marzot, Meta Berghauser Pont, Joran Kuijper (eds); *New Urban Configurations*, 2014, 480-488.
- [18] Marat-Mendes, T., Sampayo, M., Sousa-Rodrigues, D. – Measuring Lisbon Patterns: Baixa from 1650 to 2010. *Nexus Network Journal*, 2011, 13, 351-372.
- [19] Sampayo, M. and Marat-Mendes, T. – The plan permanence law in downtown lisbon maps between 1756 and 1786. In Mafalda G. Teixeira de Sampayo; Paula André; Teresa Marat-Mendes, (Eds), *Actas da Conferência Internacional PNUM 2012 – Portuguese Network of Urban Morphology*. ISCTE - Instituto Universitário de Lisboa, 2012.
- [20] Krüger, M. – *A Sintaxe da Cidade de Lisboa Contribuições Para o Desenvolvimento da Cidade*. [Syntax of the city of Lisbon, contributions to the development of the city] 1998, Coimbra: FCTUC.
- [21] Heitor, M.; Muchagato, J.; Tostões, A. – Breaking of the medieval space: The Emergence of a New City of Enlightenment. Paper presented at the Spaces Syntax Second International Symposium, 1999, Brasília.
- [22] Pearson, K. – The Problem of the Random Walk. *Nature*. 1905, 72, 294.
- [23] Krüger, M. T. J. – An approach to built-form connectivity at an urban scale: System description and its representation. *Environment and Planning B: Planning and Design*, 1979, 6, 67–88.
- [24] Sampayo, M. – *Forma Urbana da Parte Baixa de Lisboa Destruída: Análise e Avaliação da Cartografia [Urban Form of the Destructed Lisbon’s Downtown: Analysis and Assessment of the Cartography] (1756-1786)*, Ph.D Thesis, ISCTE – Instituto Universitário de Lisboa, Lisboa, 2011.
- [25] De Groër, E. – *Lisbonne exemple d’urbanisation au XVIII siècle [Lisbon, example of urbanism in the XVIII century]*. *La Vie Urbaine*, 1936, 32, 71–77.