

This is the accepted version of the article:

Leite, A., & Leitão, J. (2021). The new town of Angra (Terceira, the Azores): Confirming a contested urban planning history using reverse historical analysis and flood modelling tools. *Urban History*, 48(1), 20-36. doi:10.1017/S0963926819001093

Published version available at:

<https://doi.org/10.1017/S0963926819001093>

The new town of Angra (Terceira, the Azores): confirming a contested urban planning history using reverse historical analysis and flood modelling tools[†]

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Abstract

The Portuguese discovered the uninhabited Azores archipelago in 1427 and started to settle it during the fifteenth century. Angra, located on Terceira Island, soon became the most important Azorean city, leading to rapid urban development. This article investigates the overlooked role of streams in the rise of Angra as a pivotal Atlantic urban centre. Through the intersection of historical and flood modelling methods, it makes a unique contribution to our understanding of Angra's urban morphologic development, highlighting the potential of applying urban flood modelling to analysis of the rise of coastal urban settlement.

Water plays a central role in every settlement process; this is a universal paradigm, and it was no different in the urbanization of the then deserted Azores islands (Portugal), which occurred from the middle of the fifteenth century onwards. Existing springs and surface water played an essential role in the successful human settlement in the archipelago, providing drinking water for humans and livestock, irrigation, power to propel water wheels for mills and water to supply transatlantic ships during the age of sail as they routinely made Angra a stopping supply station. Concurrently, streams had to be controlled in order to prevent flooding and mitigate associated risks, such as damage to the built environment.

From the very beginning of the Angra do Heroísmo¹ (Terceira Island – Azores) settlement, in the late fifteenth century, various flash floods caused by intense rainfall events were reported, for example by António Cordeiro,² a seventeenth-century local historian. Significantly, present-day flooding events in Angra offer a pertinent window into the past to analyse the importance of water during the early settlement process. For instance, recent intense rainfall events and consequent flash floods reported in the town centre in September 2015 and October 2017 caused significant damage and once again

[†] The research for this article was supported by the Portuguese Science and Technology Foundation under the Strategic Project (UID/SOC/50012/2019).

¹ Henceforth referred to as Angra, since the adjective Heroísmo, which means heroic, was only added in the nineteenth century.

² A. Cordeiro [1641–1722], *História insulana das ilhas a Portugal sugeytas no oceano occidental (Angra do Heroísmo, 1981)*, 274–5.

drew attention to this recurrent problem. Despite present-day flooding events suggesting that past floods affected urbanization patterns, rarely are water management approaches correlated with Angra's urban history. Here we suggest that integrating these two approaches opens new possibilities to analyse the past through the interactions between water and its recurrent flooding events and actual settlement patterns and urban growth.

In particular, this approach casts new light on the evolution of the town plan showing how it was conditioned by the natural environment, especially water-related events. Moreover, since Angra is one of the first examples of Portuguese overseas settlement, and probably the first city to be conceived and settled outside its European territory,³ this study fits into a wider literature on early Portuguese colonial urban history. Thus, from the analysis of Angra as a case-study, we can generate other comparisons that help us understand how urban landscapes were first created during the early days of Portuguese expansion. As such, this study allows for the replication of our interdisciplinary approach to other Atlantic spaces and colonial settlements across the former Portuguese empire.

In particular, in terms of urban planning in the sixteenth century, the islands were noteworthy as a unique example of town foundation by Portugal over a long period of time. Kings Afonso III (1238–53) and Dinis (1279–1325) devoted substantial efforts to the foundation of new towns. Such dynamism in urban development in mainland Portugal slowed considerably during the following reigns⁴ – though most existing towns had expanded, such as Lisbon, where the Bairro Alto neighbourhood was built just outside the medieval walls between 1513 and 1550.⁵ In terms of urban and land planning practices as well as the development of regulations on colonization and settlement processes, the islands were also a very important precedent for the urbanization of the Portuguese Atlantic world,⁶ especially the occupation of Brazil, to which the same administrative model and settlement regulations were transferred in 1534.⁷ Thus, the main objective of this study is to shed new light on Angra's original town plan and its morphological genesis, focusing on its territorial relations and landscape integration. In short, this study aims at answering the following question: If we take the original water course and correlated flood events into account, how might Angra's urbanization process have begun?

The study territory: the Azores, Terceira Island and Angra

The Azores archipelago, comprising nine islands, is located in the North Atlantic about 1,360 km west of mainland Portugal and about 1,925 km south-east of Newfoundland in North America. It was uninhabited when discovered in 1427 and settled by the Portuguese from the first half of the fifteenth century onward. A distinctive dynamic emerged after 1474 when the archipelago was finally divided into eight donatorial captaincies, and new

³ Funchal, on the island of Madeira, was founded as a town half a century earlier and elevated to a city in 1508; however, its development was apparently not the outcome of such rigorous urban planning. Nevertheless, this is an issue that needs more study, and only future analyses can cast new light on the evolution of Funchal's urban morphology.

⁴ Only three towns were founded on the mainland after those reigns, until the eighteenth century, namely, Vila Nova de Portimão 1463, Vila Nova de Mil Fontes 1486 and Caldas da Rainha 1488.

⁵ W. Rossa, 'História(s) do património urbanístico', in W. Rossa, *Fomos condenados à cidade. Uma década de estudos sobre património urbanístico* (Coimbra, 2015), 59–80.

⁶ W. Rossa, 'Stone raft: allegory on the spread of European urbanistic in early modern times', *Joelho*, 6 (2015), 78–93.

⁷ A.R. Leite, 'Urbanística e ordenamento do território na ocupação do atlântico. As ilhas como laboratório', in J.V. Serrão, B. Direito, E. Rodrigues and S.M. Miranda (eds.), *Property Rights, Land and Territory in the European Overseas Empires* (Lisbon, 2014), 67–79.

captains were nominated to lead the settlement process in each of them.⁸ From that year onwards, new towns were founded as the centre of the newly created captaincies while, through a land reclamation scheme already implemented but improved by new legislation during this period, the territory was extensively divided and distributed among settlers using land grant donations.⁹ Land reclamation is the process by which people bring ‘unused’ or ‘waste’ land into productive use. In the Portuguese case, it was first applied through a medieval law, the 1375 Law of Sesmarias,¹⁰ which was intended to promote the occupation of abandoned rural and urban land, giving it to new settlers.

In the case of Terceira Island, in 1474, the territory was divided into two captaincies after a first failed attempt at administration and colonization of the island as a single captaincy, starting in 1450.¹¹ Both new jurisdictions, the Angra and Praia captaincies, were named after the still small settlements that had been established during the first attempts at settling the island. Located on the south coast of Terceira Island, taking advantage of the existing natural harbour, Angra – which literally means ‘port’ – soon became the most important Azorean urban centre and one of the main ports of the Portuguese Atlantic world during the sixteenth century.¹² Despite the lack of historical sources for how many people moved to Angra during those flourishing years, by the end of the sixteenth century, 100 years after the settlement began, Angra had already grown to 8,400 inhabitants. This number was exceeded only by Lisbon, Porto and Évora in continental Portugal and by Funchal on the island of Madeira.¹³

Even earlier, in 1499 – illustrating its rapid urban growth and increasing importance – Angra’s Customs House was chosen as the main location for customs in the Azores islands, due to the excellence and progressive development of the port. In fact, in the same year, on the return voyage from his first trip to India, Vasco da Gama and his crew landed in Angra. Another indicator of its rapid increase in importance was that in 1522 it was nominated to be the base for the *Provedoria da Armada*, the institution responsible for

⁸ See more about the implementation of donatorial captaincies as territorial jurisdictions and instruments of settlement in A.J.R. Russell-Wood, ‘Patterns of settlement, 1400–1800’, in F. Bettencourt and D.R. Curto (eds.), *Portuguese Oceanic Expansion, 1400–1800* (Cambridge, 2007), 161–98.

⁹ R.D. Gregório, *Terra e fortuna nos primórdios do povoamento da ilha Terceira (1450?–1550)* (Lisbon, 2007), 25–118.

¹⁰ See more details about the land reclamation process in medieval Portugal in V. Rau, *Sesmarias medievais portuguesas* (Lisbon, 1982). On land reclamation schemes in medieval Europe, see D.R. Curtis and M. Campopiano, ‘Medieval land reclamation and the creation of new societies: comparing Holland and the Po Valley, c. 800–c. 1500’, *Journal of Historical Geography*, 44 (2014), 93–108.

¹¹ J.G.R. Leite, ‘Uma floresta de enganos. A primeira tentativa de povoamento da ilha Terceira’, in L.A. da Fonseca, L.C. Amaral and M.F.F. Santos (eds.), *Os reinos ibéricos da idade média. Livro de homenagem ao Prof. Doutor Humberto C. Baquero Moreno*, vol. II (Porto, 2003), 671–6. ¹² On the Portuguese Atlantic world, see C.R. Boxer, *The Portuguese Seaborne Empire, 1415–1825* (New York, 1969), 33–134. On the Atlantic world broadly, see N. Canny and P. Morgan, ‘Introduction: the making and unmaking of an Atlantic world’, in N. Canny and P. Morgan (eds.), *The Oxford Handbook of the Atlantic World: 1450–1850* (Oxford, 2012), www.oxfordhandbooks.com/view/10.1093/oxfordhb/9780199210879.001.0001/oxfordhb-9780199210879-e-1, accessed 9 Mar. 2018.

¹² On the Portuguese Atlantic world, see C.R. Boxer, *The Portuguese Seaborne Empire, 1415–1825* (New York, 1969), 33–134. On the Atlantic world broadly, see N. Canny and P. Morgan, ‘Introduction: the making and unmaking of an Atlantic world’, in N. Canny and P. Morgan (eds.), *The Oxford Handbook of the Atlantic World: 1450–1850* (Oxford, 2012), www.oxfordhandbooks.com/view/10.1093/oxfordhb/9780199210879.001.0001/oxfordhb-9780199210879-e-1, accessed 9 Mar. 2018.

¹³ A.F. Meneses, ‘A população dos Açores em meados do século XVIII’, in C. Santos and P.T. de Matos (eds.), *A demografia das sociedades insulares portuguesas. Séculos XVI a XXI* (Porto, 2013), 167–200. M.O.R. Gil, ‘O arquipélago dos Açores no século XVII. Aspetos sócio-económicos (1575–1675)’, in *Obras de Maria Olímpia da Rocha Gil*, vol. II (Angra do Heroísmo, 2016), 300–19.

patrolling the seas and ensuring safe passage for the Indian Route through the North Atlantic return voyage to Lisbon, its final destination.¹⁴ Moreover, as early as 1534, King D. João III recognized Angra as a city and established there a new Atlantic dioceses and a bishopric for the Azores. This opened the way to reinvigorating existing urban development as expressed in its urban layout, particularly in the construction of a new cathedral (1570), a building that precipitated the reorganization of the urban fabric, which was already undergoing consolidation of its centre.¹⁵ This urban layout is precisely the town landscape represented by van Linschoten's perspective view of 1596 (Figure 1a), an image where the cathedral is actually shown under construction.¹⁶

Angra's origins through history and historiography

For many years, only two main historical sources were available, and all the facts about flash flooding were disregarded. Basing analysis on uncritical direct observations of the consolidated present urban form led to a poorly supported interpretation of the origins of urban planning in Angra. The two sources are van Linschoten's perspective view, mentioned above, which contains the oldest illustration of Angra, first published in 1596¹⁷ (Figure 1a), and the account of Angra written by Gaspar Frutuoso,¹⁸ the oldest historical chronicler of the islands, also from the last quarter of the sixteenth century.

Jan Huygen van Linschoten,¹⁹ who lived in Angra for more than two years (between 1589 and 1592), depicted the city in perspective drawn with exceptional precision and detail, specifying all the streets and houses and naming the public spaces as well as all the outstanding buildings, such as forts, monasteries, churches and the port. In fact, we can still identify most of it in today's urban plan (as represented in Figure 1b), proving it to be a very reliable historical source.

Together, both documents offer a very realistic description of Angra in the late sixteenth century. When we read Frutuoso's book describing the established city, certainly far from what the plan was in its original form, it is evident that it was an exact written explanation of the van Linschoten drawing:

This city is situated in a round, or almost round, low valley surrounded by hills... It is all very well situated, with many broad streets opening wide onto the sea, appearing very graceful, with a very wide street crossing them all. It has large houses, some with two floors, all well-built and in fine order.²⁰

¹⁴A.T. Matos, 'A provedoria das armadas da ilha Terceira e a carreira da Índia no século XVI', in L. Albuquerque and I. Guerreiro (eds.), *Actas II Seminário internacional de história Indo-Portuguesa* (Lisbon, 1985), 65–72.

¹⁵A.R. Leite, 'A sé de Angra. Cabeça do bispado dos Açores', *Norba: Revista de Arte*, 35 (2016), 27–46.

¹⁶J.H. van Linschoten [1563–1611], *A Cidade de Angra na Ilha de Iesu Xp'ão da Tercera, que esta em 39 Graos, Affbeeldinge vande Stat Angra, met het Slot op het Eylant Tercera...* (Amsterdam, 1596). <http://rmod.bnportugal.pt/rmod/winlibsrch.aspx?skey=867129D6E242418BA54590E75BF65FDB&cap=&pesq=5&thes1=4718&doc=28879>.

¹⁷*Ibid.*

¹⁸G. Frutuoso [c. 1522–c.1591], *Livro VI saudades da terra* (Ponta Delgada, 1998), 11–16.

¹⁹For an overall comprehensive testimony on the reliability of van Linschoten's work, see J.H. van Linschoten [1563–1611], *Itinerário, viagem ou navegação para as Índias Ocidentais ou Portuguesas*, ed. A. Pos and R.M. Loureiro (Lisbon, 1997).

²⁰Frutuoso, *Livro VI saudades da terra*, 12.



Figure 1. Representation of Angra's urban plan: (a) public copy: <http://purl.pt/3563/3/> Angra in 1596 (detail of van Linschoten, 1596); (b) overlay of van Linschoten (1596) detail over current Angra's urban features from one end of the city to the other.

Despite the fact that these are very rich and important historical sources for the study of Angra, it is critical to underline that both belong to the last quarter of the sixteenth century, when Angra's urban fabric was already consolidated. Therefore, these two historical sources are based on an already developed urban plan – with a clearly identified morphological unit corresponding to a planned area. This area's layout was quite distinct. In contrast with other urban areas in Angra, it exhibited a regular urban fabric organized on a pattern of parallel and perpendicular streets forming rectangular blocks.

Assuming that the plan described by van Linschoten and Frutuoso fully corresponds to the original foundational town layout, this first theory states that Angra's original plan was structured from the crossroads between Rua Direita and Rua da Sé with a square placed in the intersection of these two streets²¹ at the lower level of the water catchment,²² where, in fact, the city centre later turned out to be based.

However, this theory overlooks the fact that from its foundation, c. 1474, until the late sixteenth century when these historical sources were produced and the town plan was finally consolidated, different phases of urban formation can be identified within the regular urban fabric. These phases can be defined as follows: Phase 0: before settlement; Phase 1: from c. 1474 until c. 1500; Phase 2: after c. 1500.

Simplistic analyses based on the above-mentioned theory led to misinterpretations of the chronological process of Angra's urban development. They also paved the way for misleading interpretations, not only about the chronology of the town plan and different strata of urban history, but also regarding the urban plan's orthogonality, which seemed more regular and coherent than was usual for the period according to what was, at the time, a still undeveloped discipline of Portuguese urban planning history. For many years, these analyses maintained a foundational urban layer hidden within the urban plan and, as a result, Angra was incorrectly called the first Portuguese Renaissance urban plan.²³

²¹A theory presented in J.M. Fernandes, *Angra do Heroísmo* (Lisbon, 1989), 38, and developed in J.M. Fernandes, *Cidades e casas da macaronésia* (Porto, 1996), 178–85. J.M. Fernandes, *Angra do Heroísmo: aspectos urbano-arquitectónicos* (Angra do Heroísmo, 2008), 39.

²²A hydrological catchment is an area in which water falling on or flowing across the land surface drains into a particular water stream and flows ultimately through a single point or outlet. R.C. Bales, 'Hydrology, floods and droughts: overview', in G.R. North, J.A. Pyle and F. Zhang (eds.), *Encyclopedia of Atmospheric Sciences* (Amsterdam, 2015), 180–4. DOI: 10.1016/B978-0-12-382225-3.00166-3.

²³Fernandes, *Angra do Heroísmo*, 34.

This idea was adopted by many urban historical analyses²⁴ and was even used, among other reasons, as an argument for Angra's inclusion in UNESCO's World Heritage List.²⁵

Although we lack written sources that directly concern water events, a recent research project²⁶ has demonstrated that it is very unlikely that settlement in Angra's foundational urban fabric, dating from the last quarter of the fifteenth century (c. 1474), began in the flood-prone catchment area. Moreover, based on flood modelling analyses and other written sources, we argue that this area would often have been flooded, which suggests a different chronological sequence for Angra's urban development. The study by Leite²⁷ and the flood modelling analysis show that the downtown area was built much later, when Phase 2 of the expansion of the urban fabric was already under way. Moreover, historical reports from the seventeenth century show that the square at the intersection of Rua Direita and Rua da Sé was in fact designed and constructed only in 1611.²⁸ Additionally, in 1637, when construction was begun on the Jesuit church near the square in the north part of the catchment, the groundwater level was still high and the ground unstable, reportedly requiring complex construction works on the building foundations. Manuel Maldonado, a seventeenth-century author says that: "(...) the foundations of the Church were opened in the year 1637 (...) those on the eastern side facing Marquis Street [following Rua Direita, or Main Street] were so unsafe that they perceived it to be composed of debris from the rivers that used to flow from the heights around the city, and that they had struck what used to be the valley floor, and the old tradition says that the place where Angra's square now lies, contiguous with the Jesuits' house, was then a lagoon."²⁹

On this basis, one can argue empirically that since the town centre was naturally flood-prone, it could not have been chosen as the best location to build a new town. This option would not have been viable without applying human and material resources which, during the initial period of occupation, were simply not available. It should be remembered that during the early settlement period, the island had yet to be populated, and decision-making about where to establish human settlements could not be made without considering the natural environment and its resources.

Given their insular isolation, most likely the main concerns of the first few inhabitants were for their immediate survival and sustainability. These concerns quickly translated into decisions about where to place the emerging settlement and how to organize its population into efficient living quarters, which included the distribution of urban lots in

²⁴J.M. Fernandes, 'Angra do Heroísmo no quadro das "Cidades de Paisagem" Portuguesas medievorenascentistas', *Revista de História da Arte – Cidades Portuguesas Património da Humanidade*, 4 (2007), 213–31; M. Teixeira and M. Valla, *O los XIII–XVIII Portugal–Brasil* (Lisbon, 1999), 87–90, 98–105; T.B. Câmara, 'Urbanismo angréense: da fundação quatrocentista à cidade do renascimento', *Revista do ICALP*, 18 (1989), 108–16.

²⁵UNESCO Central Zone of the Town of Angra do Heroísmo in the Azores, 1983–2014. <http://whc.unesco.org/en/list/206/documents/>, accessed 9 Jan. 2018.

²⁶A.R. Leite, *Açores cidade e território. Quatro vilas estruturantes* (Angra do Heroísmo, 2014), 47–162.

²⁷*Ibid.*

²⁸D. das Chagas [c. 1584–c. 1661], *Espelho cristalino em jardim de várias flores* (Angra do Heroísmo, 1989), 273–4.

²⁹This is our own translation from Portuguese. In the original: 'se abrirão os alicerces da Igreja pellos annos de 1637... Estes pela banda do Leste que confronta com a rua do Marquez se achou o Centro deles nas primeiras superfícies tão mal seguro que denotarão serem compostos de hu emundice occazionada dos enchentes das ribeiras que provinhão dos altos da Cidade, e que atulharão aquele cham, que el algum tempo fora vale, e tanto assim he que tradição antiga, que o lugar em que hoie existe a Praça d Angra contiguo com o colégio era alagoa.' M.L. Maldonado [1644–1711], *Fenix Angréense*, vol. III (Angra do Heroísmo, 1989), 160.

an equitable manner and the allocation of enough land for agriculture to sustain and reproduce a growing population.

Even if we do not have documentary sources that could directly attest to the increasing volume of construction work that was aimed at drying-up and channelling the streams that used to bring water to Angra so freely, we do know that great construction works were executed during the sixteenth century in order to qualify

Angra as a city (in 1534) and as a base for the Indian Route (in 1527). Moreover, as explained above, from c. 1500 onwards the town's growth was exponential, bringing to Angra the knowledge, material and human resources needed to execute such works.³⁰ We also know that the streams were channelled in order to distribute water to public fountains and even to private houses, as represented in van Linschoten's perspective³¹ and also described by Frutuoso: "Aside from the Telhal stream, which flows from the east, near the Conception parish, another great water course runs through the middle of the city that serves twelve mills in the city...[the water goes to a] closed reservoir, from which water flows to the city by pipes and is divided amongst four main fountains, besides another that goes out near the quay, where all the navigators and floats are provided for; and in addition, it is divided amongst all the monasteries and some stately houses, with which the city is newly and freely provided; so that there are, in all, twelve fountains."³²

However, when taking into consideration the initial restrictions, a reinterpretation of archival sources triangulated with historical landscape reconstruction and urban morphological analysis reveals former historical inaccuracies about Angra's first settlement which, over time, historians have been blindly reproducing without taking into account the natural environment.

This novel methodology has made it possible to propose a more accurate interpretation of the first town plan implemented in the area. Rather than breaking with the traditional method of town foundation employed on Portugal's mainland, as suggested by earlier studies, the foundation of Angra actually appears compatible with the same medieval strategy documented in many medieval new towns founded in Portugal in previous centuries.³³

³⁰According to Frutuoso, by the end of the sixteenth century Angra had 300 masons and 150 wood workers (namely for shipbuilding). Frutuoso, Livro VI saudades da terra, 14.

³¹The channelled stream can still be partially seen in Angra's town plan in our own day, in the interior of the east urban blocks of Rua Direita in the city centre.

³²This is our own translation from Portuguese. In the original: 'Afora a ribeira do Telhal, que corre pela parte do oriente, perto da freiguesia da Conceção, pelo meio desta cidade corre outra grossa ribeira de água, a qual vem ter ao porto, com que se regam muitos jardins que nela há e moem doze moinhos dentro, na cidade, que são serventia de toda esta parte do sul, a qual ribeira procede de várias fontes, que estão quase uma légua da cidade contra uma grande serra, e ao pé dela mesma nasce outra fonte, de muita cópia de água, com arca fechada, da qual por canos vem ter à cidade e se reparte por quatro principais chafarizes, afora outro que sai junto do cais, donde se provêem todos os navegantes e armadas; e, além disso, se reparte por todos os mosteiros e algumas casas principais, com que fica a cidade muito fresca e abundante; de modo que são por todos doze chafarizes.' Frutuoso, Livro VI saudades da terra, 14.

³³On the new towns founded in Portugal during medieval times, see L. Trindade, *Urbanismo na composição de Portugal* (Coimbra, 2013).

Sources and methods

Historical written sources

Historical written sources, such as the historical iconography and cartography of Angra's foundation period, are relatively unknown, mainly because the process was poorly recorded and most documents have not survived. Nevertheless, it was indirectly documented by chroniclers in subsequent periods, such as Frutuoso's description mentioned above,³⁴ in the sixteenth century, or das Chagas³⁵ and the previously mentioned Cordeiro,³⁶ in the seventeenth. Due to the limited number of available sources, it is not difficult to enumerate those that directly pertain to the origins of the urban plan, namely, the charts of donation of the captaincies in Terceira Island dated from 1474³⁷ and the few – until now – identified letters of donation of new urban plots in Angra, dating from 1501³⁸ and 1504.³⁹ In this inventory, there is another document, dated to 1509, referring to a plot already occupied with houses being used as a payment for land sold in another part of the island.⁴⁰ One can infer from these 1509 documents that this plot had been previously bought from another owner, which provides indirect evidence of an existing urban block that had already been consolidated during the early urban phase. Further evidence derived from urban regulations of the period includes a by-law requiring urban lots to be occupied with houses for up to five years before the beneficiary resident could gain full ownership of the property, including the right to alienate or sell to others. Thus, based on this document, one can infer that this plot had already been occupied with houses since at least 1504, dating back to the donation of 1499, or most likely even earlier.

In addition, limited historical information is available about the natural stream that originally flowed through Angra's town centre. In fact, only the documents from 1474, donating the captaincies,⁴¹ and the chroniclers Gaspar Frutuoso, Diogo das Chagas and António Cordeiro refer to it. However, none of them describes the water stream in detail. They refer to it as having economic value (possessing the power to move water wheels, for example), and as an important asset for the town. For instance, in the late seventeenth century, the historian António Cordeiro describes in great detail how one of the reasons for Angra's uniqueness is that: "It is provided with so much water, that when the City wishes, it causes such a flow that when it enters the wide streets via its pavements it runs between the tiles, leaving them dry, and it drains into the sea, and the same also happens when it rains heavily."⁴²

Moreover, Cordeiro also states that, unlike most other places, in Angra no one would throw waste on the streets, since all the houses have gardens behind them, and most of

³⁴Frutuoso, Livro VI saudades da terra, 11–16.

³⁵Chagas, *Espelho cristalino em jardim de várias flores*, 260–74.

³⁶Cordeiro, *História insulana das ilhas a Portugal sugeytas no oceano occidental*, 268–74.

³⁷M. Arruda, *Colecção de documentos relativos ao descobrimento e povoamento dos Açores* (Ponta Delgada, 1989), 163–5, 173–6.

³⁸R.D. Gregório, 'O tombo de Pero Anes do Canto (1482–1515)', *Boletim do Instituto Histórico da Ilha Terceira*, 60 (2002), 89–91.

³⁹*Ibid.*, 78–9.

⁴⁰*Ibid.*, 163–5, 173–6.

⁴¹Arruda, *Colecção de documentos relativos ao descobrimento e povoamento dos Açores*, 163–5, 173–6.

⁴²This is our own translation from Portuguese. In the original: 'he provida com tanta abundancia deagua, que quando a Cidade quer, faz vir tal ribeyra della, que entrando nas largas ruas, por as calçadas dellas corre entre os ladrilhos, deyxando-os feccos, & vai parar ao mar, & o mefmo também fuccede quando chove muyto'. Cordeiro, *História insulana das ilhas a Portugal sugeytas no oceano occidental*, 274–5.

them even had access to plumbed running water inside.⁴³ In Angra, in pre-industrial times, the stream was seen as a blessing and never as a hazard or potential natural disaster even if, on occasion, it did flood the town.

The study presented in this article also relies on analysis of the current urban fabric, which, itself, must be considered as a document. As demonstrated already by urban morphological studies,⁴⁴ the built layout constitutes the primary evidence for a town's spatial development. In order to achieve an accurate result, it is essential that the studies be based on accurate cartography, such as the updated digital cartography provided for this study by the Municipality of Angra.

Reverse historical analysis and historical landscape reconstruction

Reverse historical analysis, or reverse design,⁴⁵ consists of progressively detaching urban elements from current digital cartography, following a backward chronology. Then, by mapping dated stages of the continuous urban development process, reverse historical analysis allows us to generate relatively accurate interpretations of the historical landscape for specific time periods. In addition to making possible an interpretation of the temporal sequence of urban formation, reverse historical analysis of the urban plan also provides a way to assimilate and integrate other information about a town's past that can be derived from archaeological and historical sources. It is essential that all steps of the process be informed and validated by historical sources and documents, such as those mentioned above, and corroborated by observation of the town plan layout.

When considering the water stream in the discussion on the initial stages of Angra's development, it is crucial to consider not only the documentary historical sources, but also the territory and its topographical representation. The evaluation of hydraulic behaviour during the initial period of the settlement process is as accurate as possible, as presented in the next section.

Urban morphology studies allow us to reconstruct the built environment of the past and the structure of the town, for example at the beginning of the foundational process, in order to show its historical and spatial evolution.⁴⁶ Afterwards, in order to infer the earlier stages of Angra's urban development, a reverse historical analysis was conducted to place different data sets in conversation with one another. Three principles were used. First, overlaying the earliest known mapping source, the van Linschoten portrait printed in 1596, on the most updated digital cartography, so that it shows only those morphological features that we can date from the late sixteenth century with maximum historical confidence (Figure 1b). Second, identifying those urban planning features that are most likely to be of medieval date, namely streets, plots and buildings ('plan elements' collected from the historical sources). Finally, using the variations in built form shown by patterns of streets and urban plots to identify morphological planning units, each of which nominally represents a stage in the evolution of a town's plan.

⁴³Ibid., 274–5.

⁴⁴M.R.G. Conzen, 'The use of town plans in the study of urban history', in H.D. Dyos (ed.), *The Study of Urban History* (Leicester, 1968), 113–30.

⁴⁵W. Rossa names this methodology of reverse design in the form of 'reverse engineering' postulated by Elliot J. Chikofsky in the area of computer-aided software engineering and management, as presented in W. Rossa, 'Património urbanístico: (re)fazer cidade parcela a parcela', in Rossa, *Fomos condenados à cidade*, 115.

⁴⁶K.D. Lilley, 'Mapping the medieval city: plan analysis and urban history', *Urban History*, 27 (2000), 5–30.

Geographical data and flood modelling

Geographic Information Systems (GIS) provide spatial analysis tools that can be used in decision support processes. They can provide different information and improve our understanding of various historical and geographic geo-phenomena.

GIS applications are diverse and cover various domains, including history, architecture and engineering. In the more specific domain of overland flow modelling and flood risk assessment, GIS play an important role in: (1) storing the different input data in a format compatible with urban flood simulation models; (2) pre-processing the data to clean up data artefacts; (3) visualizing the flood modelling results; and (4) assessing flood risk.

Digital Elevation Models (DEMs) represent the terrain surface and are one of the main geographic data sets involved in flood modelling, as the terrain morphology plays an important role in how water is distributed over the catchment (Figure 2a).

Other data sets used to model flood scenarios are buildings that can divert flow into the catchment area to limit the simulation domain. In this study, a five-metre horizontal resolution DEM with polygons representing the existing buildings in different stages (Phase 1 and Phase 2) of Angra's urban development were used to conduct the flood simulations. The building data were used to increase the elevation in the building locations.

Flood models can be used for several purposes, such as design, evaluation of the hydraulic behaviour and real-time operation of drainage systems, including flood forecasting. This study is the first time flood models have been used to support urban history theories in the Azores. Guidolin et al.⁴⁷ proposed the flood model used in this study; the results of the model are presented in the form of two dimensional maps of maximum water depth distribution. In Figure 2b, one can see that the results (i.e. water depth) match the water streams delineated in the cartography very well (Figure 2a).

In order to simulate the hydrological conditions of the catchment that would have affected Angra's historical centre, three design rainfall events⁴⁸ with a total duration of one hour and with different intensities (and consequently different return periods)⁴⁹ were considered (Table 1). The different rainfall intensities correspond to return periods⁵⁰ of 2, 10 and 20 years. The design rainfall events were built based on the Alternating Block Method⁵¹ using the Intensity-Duration-Frequency (IDF) curve parameters proposed by the Ministério das Obras Públicas, Transportes e Comunicações.⁵²

⁴⁷M. Guidolin, A.S. Chen, B. Ghimire, E.C. Keedwell, S. Djordjević and D. Savić, 'A weighted cellular automata 2D inundation model for rapid flood analysis', *Environmental Modelling & Software*, 84 (2016), 378–94, DOI: <https://doi.org/10.1016/j.envsoft.2016.07.008>.

⁴⁸A design rainfall event is a critical rainfall event that is used for assessing the flood intensity and duration of a certain return period.

⁴⁹ For example, a two-year return period rainfall event occurs, on average, once every two years. The longer the return period, the less likely the rainfall event is to occur and the higher its intensity.

⁵⁰A return period, also known as a recurrence interval, is a statistical average time or an statistical estimated average time between events, such as floods, to occur. V.T. Chow, D.R. Maidment and L.W. Mays, *Applied Hydrology* (New York, 1988), 466–7.

⁵¹V.T. Chow, D.R. Maidment and L.W. Mays, *Applied Hydrology* (New York, 1988), 466–7.

⁵²Ministério das Obras Públicas, Transportes e Comunicações. 'Decreto regulamentar no 23/95, 23 Agosto', *Diário da República: I Série*, 131 (1995) www.dre.pt, accessed 26 Jan. 2018.

Results

Mapping the original town plan

As mentioned earlier, a limited set of documents is available on plots related to the foundational process of Angra, but some include a few relevant elements for analysis. The documents allow for the identification of two donated urban plots (dated 1501 and 1504), plus a third property already occupied by houses in 1509, that was passed to a third owner. These documents allow for the identification of other urban elements that are referred to in the historical sources describing the precise location of the granted plots. In particular, these documents on early property ownership reveal the position of the Santo Salvador church, which was replaced by the new cathedral that was built over it in the late sixteenth century, as mentioned above (Figure 3). Moreover, it reveals the old churchyard and church front door position as well as the main chapel orientation, the location of which left its mark in the urban fabric by causing a misalignment in the street behind it. It also allows the streets where the plots were located to be identified.⁵³ By analysing the few available historical documents, such as the van Linschoten perspective view (Figure 1), and by analysis of the current urban fabric (Figure 3), it is possible to identify the morphological unit corresponding to Phase 1 (the blocks delimited by Rua do Salinas, Rua da Sé, Rua de São João and Rua da Rocha). In the van Linschoten perspective view, it can be seen that Rua da Palha is the only element that connects this morphological unit to the hinterland. Also, as can be seen today, the blocks of this unit are narrower than the neighbouring ones (which correspond to Phase 2 of the urban development).

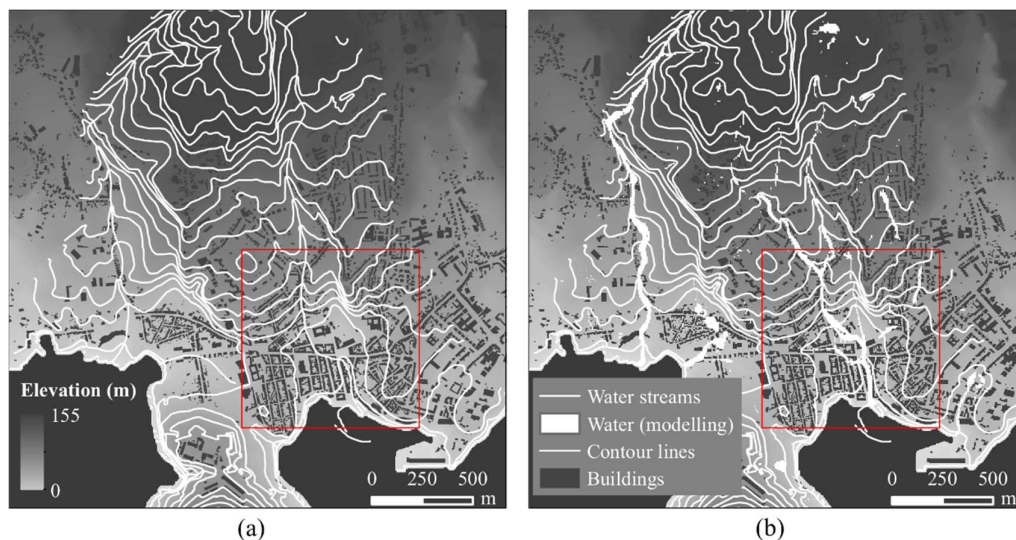


Figure 2. Catchment contributing with surface runoff to the initial settlement area (the red square shows the inset of Figure 4): (a) streams represented in the existing cartography (CM Angra do Heroísmo, 2004); (b) Flood modelling results for the two-year design rainfall.

By the beginning of the sixteenth century, new urban plots were being donated in the areas of expansion shown in the plan, namely above Santo Salvador church, to the north-west, and around Rua Direita on the south-east side of what we call the first phase. Rua Direita must originally have been Angra's main street, as it is so named in the documents donating a plot there.⁵⁴ Together with Rua de São João, they form a new morphological

⁵³Leite, 'A sé de Angra'.

⁵⁴Gregório, 'O tombo de Pero Anes do Canto (1482–1515)', 78–9.

unit very much connected with the port and related activities. This is indicated by streets that are much wider than the others in Angra's plan. Their morphology clearly shows that they belong to a different period of the town plan, giving form and space to host a new kind of urban life that ensured the development of Angra as an important Atlantic port of the sixteenth century.

Return period	IDF curves parameters			Total volume (mm)
	a (-)	b (-)	Max. intensity (mm h ⁻¹)	
2 years	162.18	-0.577	61	24.91
10 years	232.21	-0.549	81	35.04
20 years	254.19	-0.538	87	38.37

Table 1. IDF curves parameters used to generate the design rainfall events

Mapping water in Angra's urban settlement

All the water depth maps (Figure 4) resulting from the hydraulic simulations conducted in this study show that Angra's present-day town centre is flood-prone (even during low-intensity rainfall events), as empirically presented earlier in this study.

Therefore, due to the scarcity of human and material resources available on the island at the beginning of the occupation process, this area could not have been the place chosen on which to begin building a new town. Furthermore, these results also coincide with our theory, proposed via historical analysis of the town plan's origins. As demonstrated, in its first phase the town plan included four blocks and a church located on the right shore of the catchment area, bordered on the north side by a secondary water stream and on the south side by the line of the coast. This layout makes best use of the geographic and topographical conditions by locating the rectangular blocks so that the streets could run along the longer

side of the block at the same ground level, while the secondary streets, connecting the first ones, would run perpendicular to them, helping water drainage to follow the natural slope of the terrain.

In Table 2, a summary of the flood modelling results is presented for the three design rainfall events and the three occupation phases (Phase 0: no buildings, Phase 1 and Phase 2). The results clearly show that without substantial drainage works the area now occupied by Praça Velha and Rua Direita (Angra's present centre) would have been frequently flooded (statistically, once every two years). Also, the flooded area is significant, ranging from approximately 100,000 km² to almost 300,000 km² for design rainfall events of between 2 and 20 years. This underlines the fact that it is unlikely that Angra's settlement began in this specific flood-prone area.

In Figure 4, the flood maps for the three rainfall events and the three occupation phases are presented. From all nine maps, it can be seen that Praça Velha and Rua Direita are located right on top of the catchment's most relevant water line which, due to the steep topography of Angra, creates the conditions for flash flood events. Angra's drainage system (underground storm water sewer system) has normally been able to deal with these small but frequent flood events; however, for larger rainfall events, flooding has recently been reported, for example in 2015 and 2017.



Figure 3. Proposal for the location of the disappeared Santo Salvador church and current urban fabric.

Conclusions

The main objective of this study was to reveal Angra's initial urban planning, as well as to understand its foundational urban planning along with its environmental and territorial characteristics. Moreover, the study intended to rethink and provide new and more plausible explanations for how urban landscapes were newly created in the earliest days of the Portuguese expansion. In so doing, we were also able to evaluate the extent to which these newly formed Atlantic settlements were in continuity with the medieval urban settlement patterns followed in mainland Portugal.

	Max. water depth (m)	Flooded extent (> 0.1 m water depth) (m ²)
<i>2 years return period</i>		
No buildings	0.57	102,875
1st phase buildings	0.86	106,350
2nd phase buildings	0.98	109,875
<i>10 years return period</i>		
No buildings	0.71	263,700
1st phase buildings	0.91	266,175
2nd phase buildings	1.20	271,575
<i>20 years return period</i>		
No buildings	0.75	277,200
1st phase buildings	0.91	279,300
2nd phase buildings	1.28	284,300

Table 2. Summary of the flood simulation results for the three different design rainfall events and the three settlement phases.

Furthermore, as one of the first Atlantic settlements built in the age of maritime expansion, Angra could be considered a model for the creation of other urban settlements that later emerged along the Atlantic.

This study shows that Angra followed the urban programme used to settle medieval Portugal. The programme included, when and if necessary, a defence structure such as a wall or castle and, as a norm, a limited number of rectangular blocks (more easily adaptable to local topographies than square blocks) and a church – always located off-centre to the house layout. This less rigid foundational strategy, based on a more organic

model that adjusted and changed through time, allowed a flexible use of the elements, resulting in various configurations and townscapes.⁵⁵

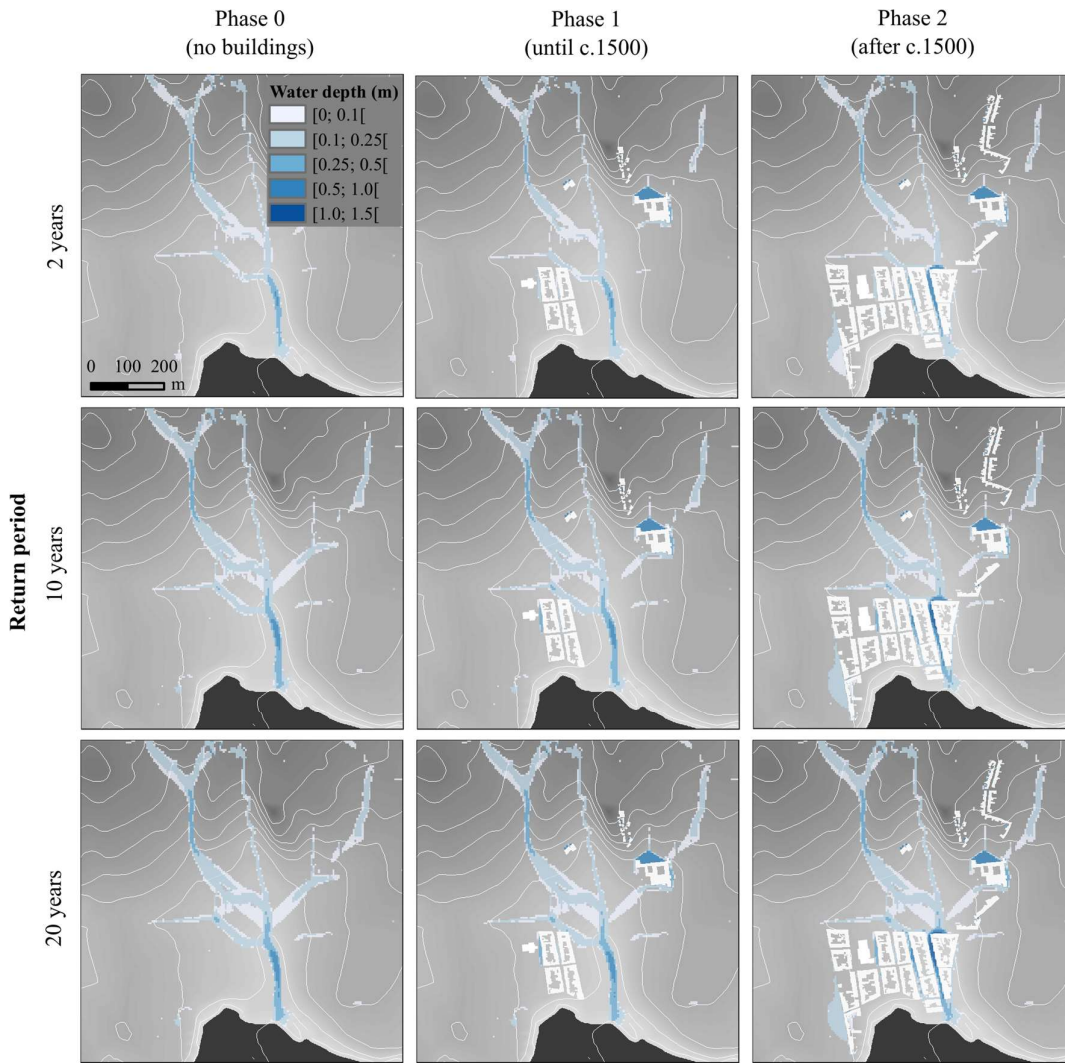


Figure 4. Maximum water depth maps resulting from the flood simulations (three different return periods and three urban development phases).

As far as the relation between the position of the house blocks and the church is concerned, Angra's foundational urban layout finds parallels with, for example, Miranda do Douro, Sines or Viana do Castelo, in mainland Portugal,⁵⁶ as well as with Praia, the already mentioned new town founded on the other captaincy of Terceira Island.⁵⁷ This clearly indicates that, instead of relying on theoretical models of dubious applicability in order to face the uncertainties of a new world, the Portuguese option was to rely on known strategies that had been tried before with success.

As demonstrated in this study, flood models can also be successfully used to support historical investigations of urban development. The flood model applied on Angra's territory proved that the town centre (Rua Direita and Praça Velha) is prone to flooding,

⁵⁵Trindade, *Urbanismo na composição de Portugal*, 117–60.

⁵⁶In *ibid.*, respectively 306–16, 387–404, 460–76.

⁵⁷Leite, *Açores cidade e território*, 163–229.

showing that this area could hardly be viable as a permanent place for settlement without making huge investments of material and human effort. This confirms the results obtained from the historical data previously collected and analysed, demonstrating that the lower catchment area was only urbanized during a second phase (Phase 2) of town building, indicating a very different chronology from that informing most historical studies.⁵⁸

The analyses also allowed us to identify a more precise definition of the morphological town units corresponding to each phase of the urban layout, as well as to confirm the position of other plan elements, such as the two urban plots donated to the settlers and the Santo Salvador church which had already been demolished.

From all the analyses presented in this article it was possible to propose a more accurate basis for Angra's foundational plan, very different from that considered in previous studies, and which for many years informed Portuguese urban history.

The novel theory for the urban development of Angra presented in this study and supported by various historical and flood modelling analyses, can become a new milestone for interdisciplinary collaboration studies that has the potential to reveal determining factors in urban planning history which are too often overlooked.

⁵⁸For such studies, see Fernandes, *Angra do Heroísmo: aspectos urbano-arquitectónicos*, 39.