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Unsustainable Cities, a Tragedy of Urban Networks

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This article aims to understand urban un-sustainability. First we review some paradigmatic cases of unsustainable cities, namely Easter Island, Mayan cities and Santa Maria Island. Then, we briefly review operational urban simulation models and sustainability with particular focus on spatial interaction models with land use. We apply an operational urban model with the use of natural resources to perceive the past and future history of the development of one of the smallest cities of the world, Corvo. We show that, in unsustainable cities, technological inadequacy leads to irreversible degradation of the natural capital and institutional inadequacy enables free access to the urban space, creating a "tragedy of urban networks".

1. Introduction

Overall sustainability is a recurring challenge and, to date, a markedly hypothetical one, whose conceptualization has evolved throughout the development process, repeatedly overcoming fears concerning sustainability. Take three remarkable examples. First, the theoretical paradox of Thomas Malthus (1798) on the potential imbalance between supply and demand for food, which was surpassed by the various green revolutions that resulted from the interaction between technological evolution and institutional adequacy. Second, the argument presented in “The Limits to Growth” (Meadows et. al., 1972) was followed by an unprecedented process of economic growth with visible progress in the creation of effective environmental policies. And third, more recently, the declaration of inter-generational justice, proclaimed at the World Summit for Sustainable Development (United Nations, 2002), which is in large part contemporary to phenomena such as the dematerialization of the economy underlying the rise of the knowledge society.

There are however two important issues in this provocative introduction to the concept of global sustainability. The first concern has to do with ignorance about the functioning of ecosystems and the goods and services generated from them, which not only has justified precautionary measures regarding the environment but also justified an increased research effort on the productive and creative potential of ecosystems. The second issue relates to the elusive disregard of unsustainable tragedies that have occurred at local and regional level along the history of mankind. Tragedies that were intrinsically linked to unsustainable cities led to the many ruins scattered around the world:

Anchor, Knossos, Zimbabwe and Chichén Itza as well as many others described in the book "Collapse" by Jared Diamond (2005). The following questions arise: How to explain the disappearance of those cities and civilizations on the basis of a theory of sustainable cities? How to prevent existing cities from becoming unsustainable and ruinous?

The aim of this paper is to frame these questions, going beyond markedly ideological texts that justify contemporary urban policy, particularly since these ideological statements are usually associated with uncritical deployment of technological solutions that can be truly unsustainable in the long term. At the end of the day we look into urban theoretical models and operational concepts and tools in order to understand the history and design urban policies suitable to create sustainable future stories.

The issue is important because the demand for and innate dependence on environmental goods and services are increasingly rooted in the cities. Cities which increasingly concentrate more population grow in sensitive coastal areas, consuming more and more water, energy, soil, space for waste and natural environments in terrestrial, aquatic and atmospheric systems (Haughton & Hunter, 1994, 1996, 2003, 2004) create impacts and effects that quite often are not well perceived by the cities and therefore not internalized into the procedures of urban management. In this sense, the city cannot be seen as just an urban consumer environment potentially doomed to disaster but as systems involving the urban area and the surrounding environment that complements the city.

The approach to the issue of urban sustainability is thus consistent with the approach to sustainable development (Satterthwaite, 1997). Moreover, sustainability is strongly linked to urban density (Jenks & Burguess, 2000) and to the structure of transport networks (Banister et. al., 1997) although in a complex and nonlinear manner because there are environmental factors and acceptability features that go against the simplistic view that more compact cities are more sustainable (Williams et. al., 2000), all this revealing factors and tools for managing sustainability. These factors have long underlied urban planning and infrastructure deployment, particularly in issues related to the size and location of cities, the interactions between developed and undeveloped spaces, and, to a smaller scale, the design of blocks and housing.

However, cities evolve from their unsustainable features, and although there may be prospects for intervention to encourage discussion and to evaluate pre-defined scenarios of urban forms, the truth is that various urban forms can evolve and coexist into compact forms, contained towns or linear cities (Williams et. al., 2000), resulting from the interaction between internal and external markets, from land use, from the surrounding environment and from the multiple levels of regulation (Bulkeley & Betsill, 2005) that shape the culture of the city.

The shape and culture of cities are the result of the accumulation of more or less effective responses to new and recurrent challenges: challenges facing poverty and urban growth in developing countries; challenges in transport, expansion and the environmental quality of cities in developed countries (Nijkamp, 2008). The quality of governance can be assessed by the competitiveness of cities and towns from which it is easy to identify winners and losers and, based on conceptual models, discover the environmental, technological, economic and regulatory factors that try to explain the better or worse performance of the cities.

Peter Nijkamp (2008) explores the perspectives of the current literature on cities (models of urban markets, eco-cultural urban models, models of urban agglomerations and industrial networks, political models, models of urban agglomerations, urban innovation models and models of virtual cities) and proposes a systemic approach that integrates the positive and negative economic externalities associated with density (Camagni et. al., 1998), considers the resources that sustain the cities an takes into account the creativity for technological and institutional innovations in cities. The perspective of this paper is similar but instead of only examining central cities, it starts looking at cities that disappeared or may disappear, without restraining itself only to those that, being more central, are let die or degrade as part of the urban fabric.

To this end, we review in section 2 some case studies of unsustainable cities. In section 3 we formulate an urban operational model which incorporates the use of natural resources in order to replicate past history and simulate the future history of one of the smaller cities of the world, the Corvo Island in the Azores. Finally section 4 presents the conclusions of the paper and reviews the recommendations underlying ideological texts on contemporary urban policy.

2. Cases of unsustainable cities

2.1.Easter Island

Easter Island is one of the clearest examples of an unsustainable city (Figure 1). It was occupied between AD 600 and 900 by the Polynesian people who came to stay isolated from their origins. When Westerners arrived in the seventeenth century they found a society in decay, an island with no trees and no boats. According to Jared Diamond (2005) the cause of the lack of sustainability of the island was not due to external attacks, to broken links with friends or to climate changes, which also occurred during years of population growth.

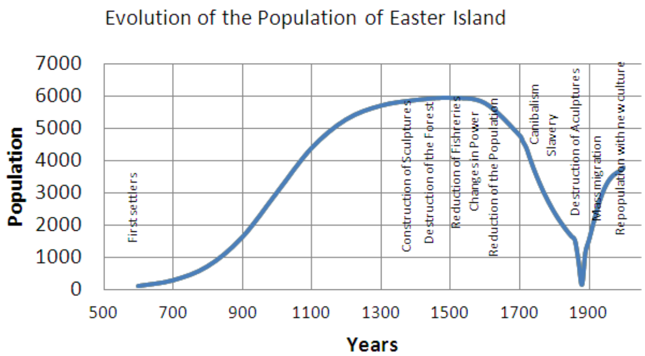

Figure 1. Evolution of the Population of Easter Island (data from Diamond, 2005 and other sources)

The author's argument is that the collapse of that civilization was due to an overuse of the forest and to deforestation, which precipitated a shortage of trees to make canoes, to fish and to erect statues, and to the inability to emigrate. It was ultimately due to the creation of crystallized political, social and religious institutions which during the period of decadence, promoted war and destruction, subjugation and hegemony from each other, cannibalism, slavery and also to a reduced resistance to smallpox, tuberculosis and weak resilience of society against the slave trade and mass migration at the end of the nineteenth century. Summing up, what occurred was a genuine inconsistency between, on the one hand, the natural and manmade environment and, on the other hand, the economy and the institutions.

2.2.Mayan cities

The ruins of the Mayan cities show another form of unsustainable cities. This was not a case of small communities and remote regions such as the Easter Island civilization but of large continental and structured cities/kingdoms relatively isolated from each other that were depopulated and ruined, as shown in Figure 2 for the cities/kingdoms of Copan, Puuc and El Mirador. They became unsustainable due to environmental reasons (soil erosion of hills and plains, and land degradation in addition to long periods of drought), to technological causes (a family of farmers could feed no more than just a family of a non-farmer), to economic factors (the difficulty of transporting and storing products which led to the existence of isolated, punctual and non diversified markets) and institutional causes (an aristocracy unable to find ways to resolve the institutional crises except through war and conflicts between kingdoms).

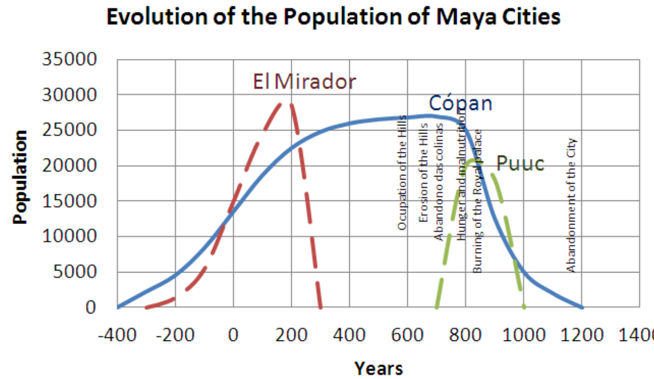

Figure 2. Evolution of the Population of Mayan Cities (data from Diamond, 2005 and other sources)

However, as interpreted by Jared Diamond (2005) the story is more complicated. On the one hand, the collapse of a city may have been followed by the growth of another, or simply by the dismantling of civilization and maintenance of the population. On the other hand some areas were much more affected than others, especially those less resistant to drought. This was the case for example in the Petén region where, from a population of 3 to 14 million, the Spaniards only found around 30 thousand in the sixteenth century, a number which decayed to 3 thousand by the eighteenth century.

2.3.Santa Maria Island

A little closer to us in time and space, the Santa Maria Island is also a good example of a non sustainable city / island, not so much because of economic cycles that characterize all cities but by the destruction of the economic potential of the city/island by abandonment or dilapidation of human and environmental capital, and not so much due to an institutional incapacity to meet challenges but for lack of local capacity to preserve and develop the environmental and human capital needed to build up new cycles of competitive advantages.

The importance held by the island in the Atlantic sea lanes in the early settlements (XVth century) moved to the bigger nearby islands of San Miguel and Terceira. The importance it had in the beginning of the transatlantic military air routes (1944) passed to Terceira Island, where the Lajes airfield was built and has been used since World War II. In the fifties and sixties of the XXth century Santa Maria played an important role for civilian air transportation in the transatlantic routes and in the traffic distribution in the Azores. Nevertheless it was not

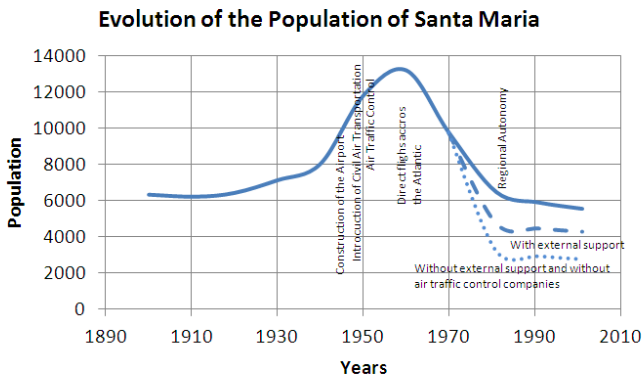

Figure 3. Evolution of the Population of Santa Maria Island - Azores

was done in other local airports, first with free zones and later as hubs of low cost airlines. Even the recent decision by the ESA, European Space Agency, to install a mobile tracking station on the island to control the satellites routes seems to be always dependent on external decisions, despite more than fifty years of experience in air control; this type of human capital has not generated stable roots in this area.

Moreover, the productive capacity of the island would had been half of what it was in the thirties, had it not been for substantial external support since the establishment of autonomy in the Azores in the mid seventies of the XXth century – associated with the creation of government jobs financed by external taxes - and if three hundred employees in support of air navigation had not been maintained. This air control activity could have been moved to the United States of America in the nineties. Indeed, the creation of the airport not only brought people from other islands and mainland Portugal, but also triggered migration from rural areas to the main town close to the airport, leading to the abandonment of fields which are unlikely to recover their previous vocation.

2.4.Lessons from the Case Studies

In short, the sustainability of cities is not a theoretical question; proof of this can be found in the many urban ruins that we discovered and visited, and upon which we raise questions about sustainable civilizations or cities. That sustainability crucially depends on the management of four types of strongly interlinked capital:

- Environmental capital that can be destroyed by natural causes or degraded by poor management of men. That can happen to many coastal areas with an increase in the average level of the sea or to many areas where climate change can cause changes in the hydrological cycle.
- Technological capital also called adapted spaces, which may become obsolete or inappropriate as happened to the Santa Maria Airport in the face of technological developments of air transportation, as with many historic urban centers facing the automobile revolution and, more recently, as we are observing in many urban neighborhoods facing the rising cost of energy and car transportation.
- Human capital that can migrate or degrade. That is also what happened in Easter Island with the replacement of political leaders by warlords, in Mayan Cities with the deposition of kings, and in Santa Maria Island with the lack of integration in island society of air control experts, who therefore are always ready to migrate to other places.
- Institutional capital, revolutionized and inappropriate on Easter Island, self-destructed in the Mayan civilization and external and not rooted on the Island of Santa Maria.

In fact the main cause of the un-sustainability of cities seems to be an incapacity to create institutions that encourage the efficient management of natural and environmental resources, and an inaptitude to generate technological adaptations to the challenges of the economy and the environment and the promotion of human capital.

3. Operational Urban Simulation Models and Sustainability

3.1.Spatial Interaction Model with Land Use

Our model of spatial interaction is constructed from a base model (Costa, 2002) which in turn is a modification of the Keynesian model of actual demand, assumed to equal total employment income (Y), (E_t <=> Y), which in turn arises from base employment which is generated by exports (*E*) (E_b <=> *E*) and non-base employment which is given by consumption (C), plus investment (*I*) plus government spending (G) minus imports (M) (E_n <=> C + *I* + G – M).

In the base model it is assumed that there is a fixed ratio (s_k) between the population (*P*) and the Non Base Employment (E_{kn}) by type of activity (*k*) ($P/E_{kn} = s_k$) and that the relationship between Population (*P*) and Total

Employment (E_t) remains constant ($P/E_t = r$). Since total employment is the sum of base and non-base employment for various sectors of activity ($E_t=\Sigma_k E_{kn} + \Sigma_k E_{kb}$) it is easy to calculate the Keynesian income multiplier that relates total employment (E_t) and population (P) to base employment ($E_t = (1/[1 - r\Sigma_k s_k]\ (\Sigma_k E_{kb}))$; $P = (r/[1 - r\Sigma_k s_k])\ (\Sigma_k E_{kb})$).

What our spatial interaction model adds to the base model it is to recognize that employment and population are located in various parts of the study area and that commuting - explained by gravitational formulas - occurs from employment to residence and from residence to services (and that there exist jobs which are associated with it). Our model distributes residents around employment sites and services around residences given distances and attractiveness per area. The equilibrium between supply and demand for land is achieved by the calibration of the attractiveness of each location and its capacity, assuming that the attractiveness is strongly related to shadow rents of comparable places and respective capacities.

The model consists of equations Eqs (1) to (4). The population living in each zone is dependent on base and non-base employment in various sectors, which is established in all other areas:

$$T_{(ikl)j} = rE_{ikl}\left[(W_j \exp(-\alpha d_{ij}))/\Sigma_j[W_j \exp(-\alpha d_{ij})]\right] \quad (1)$$

$$P_j = \Sigma_{ikl}\, T_{(ikl)j} \quad (2)$$

where $T_{(ikl)j}$ is the population that lives in j and depends on the activity k in the soil class l in zone i; E_{ikl} is the employment in sector k of soil class l in zone i, r is the inverse of the rate of activity; W_j is the residential attractiveness or area j ranging between 0 and 1; α is the parameter that defines the attraction in terms of distance; d_{ij} is the distance between i and j, and P_j is the total number of residents in j.

Moreover the activities generated in each zone to serve the population living in all other areas within a range of service are given by:

$$S_{i(kjl)} = s_k P_i\left[(V_{lj} A_{lj} \exp(-\beta_k d_{ij}))/\Sigma_{lj}[V_{lj} A_{lj} \exp(-\beta_k d_{ij})]\right] \quad (3)$$

$$E_{jkl} = \Sigma_i\, S_{i(kjl)} \quad (4)$$

where $S_{i(jkl)}$ is the activity generated in sector k in soil class l in zone j that serves the population in zone i; V_{lj} is the attractiveness for services of soil class l in zone j; A_{lj} is the area of class l soil zone j; s_k is the ratio of non-base employment activity k over population; the parameter β_k defines the friction produced by distance for people who seek services activities in sector k, d_{ij} is the distance between i and j.

The parameter α is calibrated so that the average cost of commuting from home to work is similar to the average cost observed in reality. Similarly, the parameters β_k are calibrated following the same logic as before, ensuring that the average cost of service k for the population is very similar to the current average cost.

However, some spatial constraints that must be satisfied. The area occupied by different activities (base, non-base and residential) in every zone i, and for each soil class l, must not exceed the total area A_{il} [Equation. (5)].

$$\Sigma_k[\sigma_k S_{ij}] + \rho P_{ij} + \Sigma_{ik}[\sigma_k Eb_{ilk}] \le A_{il} \quad \text{(for all classes } l \text{ and zones } i\text{)} \quad (5)$$

where: σ_k is the area occupied by employment in sector k, ρ is the area occupied by a resident; A_{il} is the area available for class l in zone i.

It is important to note that, in Equation (5), different sectors k compete for space in each class l and zone i. To solve this problem, the attractiveness V_{lj} of soil class l in zone j must be calibrated to ensure that the conditions of Equation (5) are met. In this paper we apply an interactive calibration of (V_{lj}) according to expression (6)

$$V_{lj} = 1/[1+\exp(-\varphi(\delta_q + \delta_{q-1})] \quad (6)$$

where $\delta_q = \{\Sigma_k\ [\sigma_{k\ q} S_{ijk}] + \rho_{\ q} P_{il} + \{\Sigma_{ik}\ [\sigma_k\ Eb_{ilk}] - A_{il}\}$ for each iteration q and θ is the parameter which controls the pace of the calibration process. Note that the calibration process of V_{lj} ends when the land use of each class l in zone i does not exceed the amount of area available A_{il}. It follows that the attractiveness of each calibrated soil class l for each zone j can be interpreted as the bid-rents associated with each soil class in each area (ω_{lj}). In fact, if we assume that (7) holds,

$$\omega_{lj} = \ln(1/V_{lj}) \quad (7)$$

expression (3) then takes the form:

$$S_{i(kjl)} = s_k P_i\left[(A_{lj} \exp(\omega_{lj} - \beta_k d_{ij}))/\Sigma_{lj}[A_{lj} \exp(\omega_{lj} - \beta_k d_{ij})]\right] \quad (8)$$

where the bid-rents (ω_{lj}) are complementary to transport costs as expected in models of spatial equilibrium. Residential attractiveness is defined by areas while the attractiveness of services is established by areas and soil class.

In the present model, we assume that the attractiveness for different residential areas is expressed as a linear combination of the maximum and minimum attractiveness of each zone for different classes as follows: $Wj = \varsigma\ Max_l(V_{lj}) + (1 - \varsigma)\ Min_l(V_{lj})$, where ς ranges between zero and one.

Endogenous variables (P_i, E_{kj}) can be obtained from the exogenous variables on base employment (Eb_{ik}) through the use of matrices *[A]* and *[B]*.

$$[E_{ik}] = \{I - [A][B]\}^{-1}[Eb_{ik}] \quad (9)$$

$$[P_i] = \{I - [A][B]\}^{-1}[Eb_{ik}][A] \quad (10)$$

where $[A] = [\{rW_j \exp(-\alpha d_{ij}) / \Sigma_j[rW_j \exp(-\alpha d_{ij})]\}]$ and $[B] = [\{s_k.A_{lj} \exp(-\omega_{lj} - \beta_k d_{ij}) / \Sigma_{lj}[A_{lj} \exp(-\omega_{lj} - \beta_k d_{ij})]\}]$.

3.2.Spatial Interaction Model with Land Use to Analyze Urban Sustainability – the Case of Corvo.

Corvo Island is one of the smallest and most remote towns in the world. What makes it a town is the fact that it has all the functions that a town has: export activities, school, health center, town hall, electricity generation, banks, restaurants, cafes, households, port, airport, fire station, water supply, waste collection, sanitation, political representation, etc. What makes it small is that it has only 440 residents, 100 acres of area with fresh fruit and vegetable cultivation capacity, 1,600 hectares of adjacent land and, coupled with its Atlantic centrality, a huge exclusive economic zone that gives it relevance. There are and have been many cities like that around the world; many of them have disappeared because they have become unsustainable, and this has not caused any global concern. However, from the viewpoint of regional economics, the accumulation of many cases of such non creative destruction is gaining relevance. It is therefore of interest to look at the history of Corvo Island, using a spatial interaction model with land use, as presented in the previous section, and to try to understand the sustainability of development in Corvo Island.

The settlement of Corvo originated in the late sixteenth century and in 1590 there are records of a population of about 80 people which, given the productivity of land, the population and the pattern of consumption and exports had a foot print similar to that shown in Figure 4 (1590). The population grew until the mid-nineteenth century.

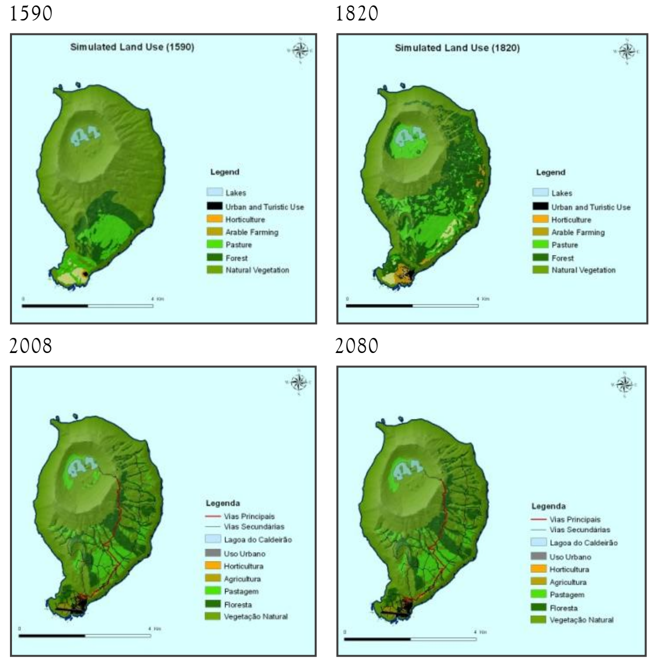

Figure 4. Evolution of Land Use in Corvo Island

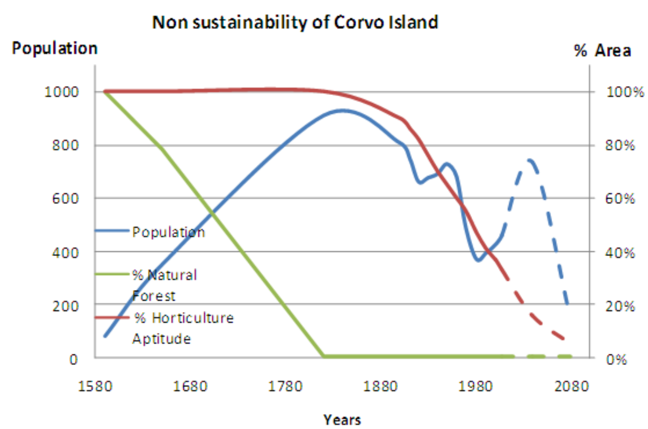

Figure 5. Evolution of Land Use in Corvo Island

In the nineteenth century population pressure completely ruined the original forest on the island, destroying every tree; institutions did not improve afterwards with the regime of free access to higher areas by cattle that followed this destruction. Fuel shortages and the possibility to emigrate explained the continued decrease in population since the nineteenth century with a small reversal in the years following the Second World War, possibly with the introduction of fuels as alternatives to firewood and the greater economic dynamism of the Azores, and beyond, after regional autonomy was introduced in 1976 until 2008 with the addition of public transfers to the island. The continued destruction of the small area with the capacity to produce fresh vegetables and fruit (which could be imported but at high costs) make the overall competitiveness and sustainability of the island more problematic.

The scenario for 2080 stems from an assumed increase in population by increasing tourism and fishing, which results in a greater spread of the urban area up to the small area with capacity to produce fresh vegetables and fruit. Naturally, after the impact of a cycle of tourism and a lack of care in preserving the capacity for sustainable development of the economy, the population of Corvo Island would be expected to have fallen by 2080 (Figure 5).

4. Conclusions

The application of the spatial interaction model with land use to the case of Corvo Island has illustrated perfectly how versatile and comprehensive this tool is for combining in a consistent way data from such diverse fields of study as environment, agriculture, economics and demography, as well as data from different data bases, such as cartographic and non-cartographic, and from different timelines, as we have shown by pulling together data from the XVIth through the XXIst centuries.

The main conclusion of this article, illustrated by the presented case studies and by our own work in Corvo Island, is that urban un-sustainability is created by technological and institutional inadequacies. Technological inadequacy leads to an increased and irreversible degradation of natural capital in the long term, which, for the limited space of a city, is a complement and not a substitute for technological capital. The institutional mismatch allows the free access to urban space by creating its own mechanisms of the "tragedy of the commons." It is the free access that promotes the spread of infrastructure and urban services based on the payment of the average cost for its provision. It is the free access that underlies the politics of urban zoning but at the same time, undermines the adjustment mechanism of land rents.

Summing up, cities have sustainability problems but cities are not a problem in themselves; problematic are the government failures that create urban problems because they are not transformed into challenges (Jenks & Burguess, 2000), leaving no room for technological and institutional innovation and thereby precipitating the un-sustainability of cities.

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