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The role of density and population size in the pandemic-crisis experience of Covid-19

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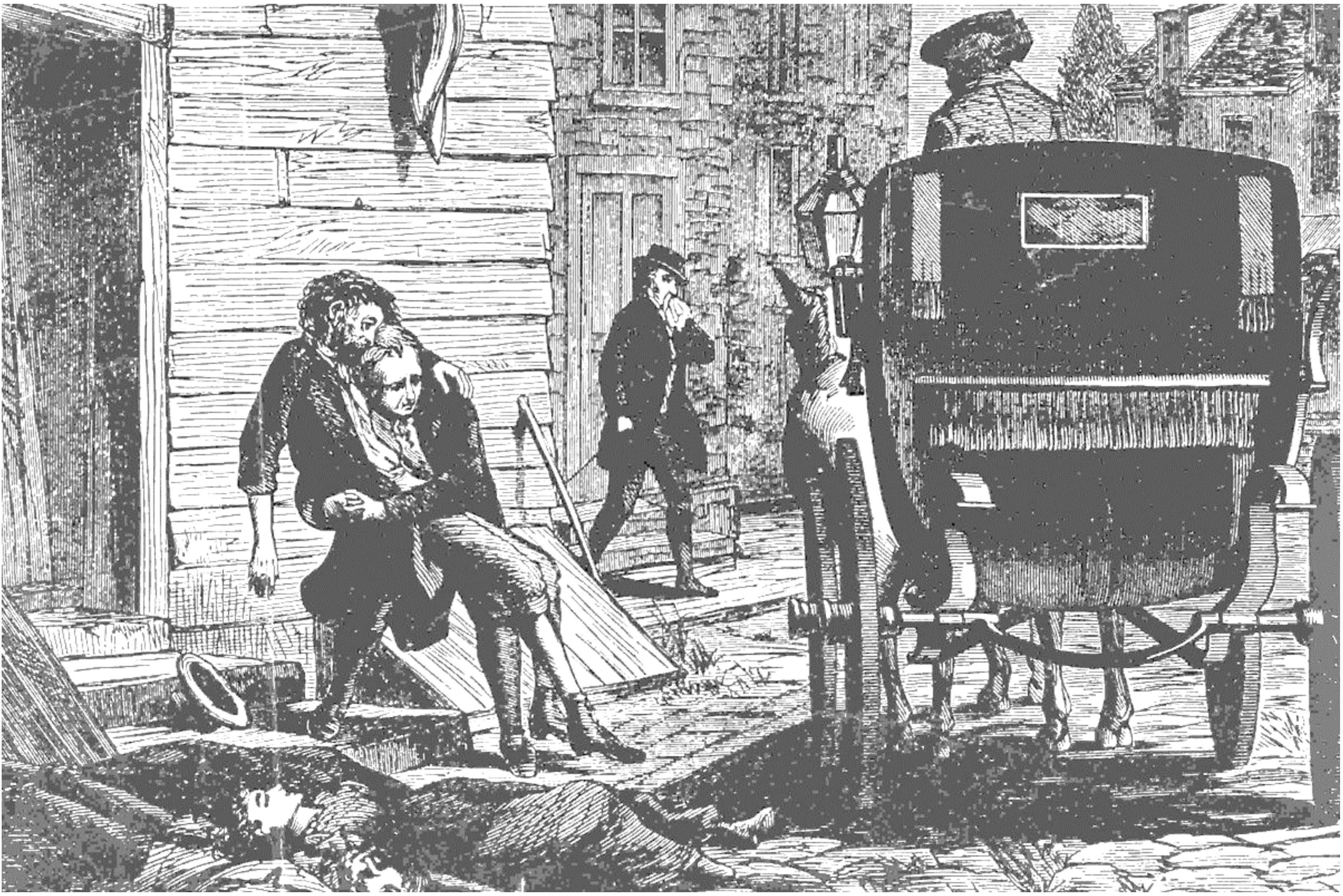
Alessandra Buffa
Turin, October 2022

The yellow fever will discourage the growth of great cities in our nation; and I view great cities as pestilential to the morals, the health and the liberties of man.

Thomas Jefferson, 1800

(Thomas Jefferson to Benjamin Rush, September 23, 1800, The Thomas Jefferson Papers at the Library of Congress - General Correspondence).



Artist interpretation of the yellow fever epidemic in Philadelphia in 1793. As the virus sickened thousands, a U.S. founding father turned to two Methodists for help. Print from Bettmann Archives.

Abstract

The unexpected situation of COVID-19 highlights the urgent knowledge need for integrating urban disciplines and public health subject. More specifically, the academic debate around the relationship between the spatial dimension and COVID-19 diffusion points out, among the others, a question: what is the role of a larger population density, or a larger size of the population in the diffusion of the COVID-19 virus? To provide and support an answer in the US metropolitan context, proper reflections should be taken to deal with three highly significant determinants of the spatial shape of the COVID-19 diffusion: the situation in terms of density and population size, the metro condition (separately from the non-metro division) at the county level, and the pandemic determinants in a specific phase of the pandemic. To carefully understand the effect of population size and density at the US county level, the thesis firstly explores the key theories referred to diffusion theory and complex urban systems, and then moves to an analytical and practical part. In this quantitative experimentation, the work distinguishes a group of "COVID-19 variables" and another heterogeneous collection of "COVID-19 reaction variables" which allow measuring, on one side, to what extent a pandemic wave behaved in a certain season, and on the other, in which kind of geographical and socio-economic context the surge impacted within the season observed. These interaction-variables have been collected distinguishing between metro and non-metro counties and are able to address some socio-cultural and economic differences that may have played a role in dealing with the virus.

To generally interpret the results from the single and multiple regression analysis and from the correlation and multicollinearity tests, there is no sufficient evidence to state that population density and size positively correlate with COVID-19 spread, since evidences from data-processing do not allow to assume rigid positions on that. They are mainly inter-related with the other independent variables, but less with the behaviour of COVID-19 cases and victims. However, as the literature suggests, while in the early phase of the pandemic, density had often a positive impact only in metro counties, then in later phases the effect of density decreased, in favour of other variables covering a greater role than expected.

The thesis effort of combining these different topics and dimensions has the potential to provide a ground-breaking contribution to the research on COVID-19 diffusion at the spatial

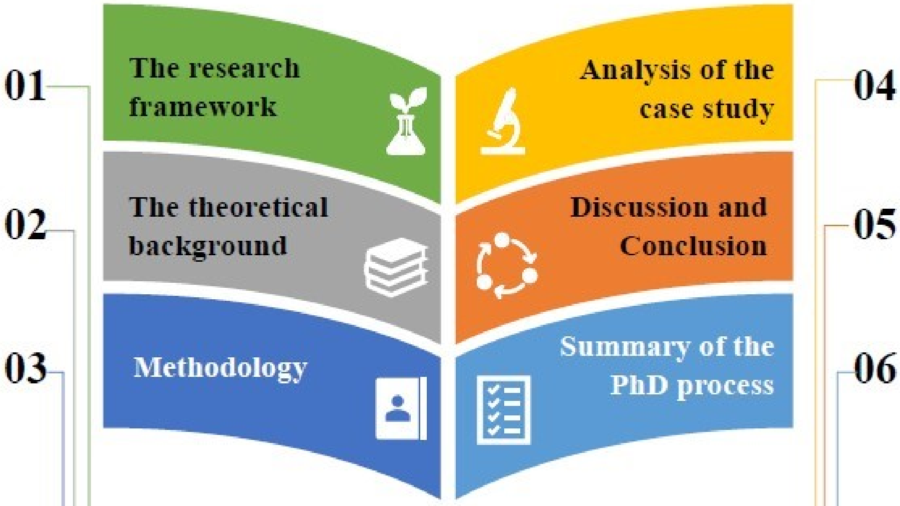
level, as several built-environment properties will be "tested" in terms of efficacy along the crisis-steps and then will be probably discussed and re-organized (Samuelsson et al., 2020). Therefore, this work will firstly require extensive theoretical labour to collect the properties to address the research statement, and then a big data collection, processing and understanding, to provide first and reliable answers.

Insights of this research will certainly propose a new mix of disciplines, offer new perspectives for understanding the element of change in metropolitan counties, and advance the field of planning by understanding beyond their current state. In this scenario, the application of evolving concepts like diffusion theory applied to COVID-19 behaviour, system and complex theories, resilience perspective and adaptation approach may provide new insights for planning science and practice.

Finally, yet importantly, at the current time, this work does not know yet which changes will occur in people's everyday urban life in the long-term, since the COVID-19 pandemic is still a relevant and existing topic. However, because of its global extension and spatial impacts, the vaccination process going on and the progressive confidence and coexistence with it, it is reasonable to sustain that urban contexts and functions may be (highly) affected by COVID-19 impacts and may not be able to go easily back in their business-as-usual habits as if nothing had happened. A deeper analysis in this sense will be beneficial to introduce the acceptance of the new crisis regime in the Anthropocene Era.

Keywords: COVID-19, density, population size, diffusion, planning, resilience, change

The Road Map of the Thesis



This introductory chapter aims to offer a first narrative of the thesis-work, while structuring the thesis framework according to its key issues: aims, questions, boundaries, limitations, contributions and target subjects.

In this chapter of the thesis, the topic of the work is presented and deepened, through the use of theories, concepts and literature contributions.

Chapter Three explains the methodology approach applied, focusing on the typology adopted (and recognized in literature) and then moving to the variables selected for the case study analysis.

The goal of this chapter is to provide, starting from the theoretical framework described in Chapter 2 and the crisis context of COVID-19 described in Chapter 3, an empirical assessment of the interactions between the dependent and independent attributes described in theory.

This chapter, based on the previous theoretical and practical ones, addresses the research questions with more awareness and arguments, and provides some conclusions about the work.

This chapter, which is mainly a conclusive report of the PhD activities, highlights the key parts of the PhD process with a holistic approach.

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CHAPTER 1

THE RESEARCH FRAMEWORK

This is not just a public health crisis, it is a crisis that will touch every sector – so every sector and every individual must be involved in the fight.

I have said from the beginning that countries must take a whole-of-government, whole-of-society approach, built around a comprehensive strategy to prevent infections, save lives and minimize impact.

WHO Director-General, Dr. Tedros Adhanom Ghebreyesus, 11 March 2020

The narrative of the thesis-work

When between the end of February and beginning of March 2020 the first news about the novel coronavirus "SARS-CoV-2"[1] *(then named in the text "COVID-19") started to spread globally, in a more worried and serious way, I was in Sweden to fulfil my visiting period abroad at Chalmers University of Technology in Göteborg. My research orientation and focus at that time were still at a very early and undefined stage, and one of the objectives of my stay was indeed to find a proper "case study" to work on. Ironically, I was in search of a crisis experience challenging an urban context, in order to analyse and verify its capacity to deal, fight and respond. Then, very quickly and unexpectedly, those "far news" about COVID-19 came closer and, sadly, they forced me to return to Italy in advance, interrupting my visiting-period in Göteborg definitely.*

Back to Turin and full of desolation, one morning – on national lockdown – while breathing some fresh air on the balcony, I got an inspiration: "why don't I focus on COVID-19? Isn't it a "perfect" crisis-experience challenging, among the others, the urban dimension?". After all, I thought, despite at that time we did not have so much information about the virus, it was

[1] While the name of the infection of novel coronavirus is "SARS-CoV-2", the infectious respiratory disease is usually called "COVID-19". Within this thesis, COVID-19 will be applied as the "dominant term" referring to this pandemic, with only exception for specific quotations, declarations or studies around the corona-virus itself.

already quite clear that its consequences would have deeply touched the globalized-system in which we live. In fact, among the first articles and reflections on this global infection, one topic had already started to return: the long-term effects that the COVID-19 crisis will have on the globalized cities and the changes that, once we get through this, will transform cities forever. Particular attention, in this early debate, was given to the ongoing and strong relationship between cities and densities, and to the fact that the latter may have favoured the rapid diffusion of the virus. The argument that dense urban settings are bad for people's health is not new but, I thought, this new virus – happening in a very critical and contemporary moment of our Anthropocene time (where, to name one, also climate change is challenging our systems and behaviours deeply) – has the potential to become an interesting and transversal topic touching basically every field, from health to policy, from planning to design, from sociality to economy, and so on.

This challenging and uncertain perspective gave me back a good motivation to start collecting all the possible written material on COVID-19 and urban contexts and read, read and read, so as to understand what the most prepared experts were going to state, criticize and expect.

In these months of full reading, I found that the debate on COVID-19 diffusion and urbanized contexts was actually observing (and blaming) few cities in the world. New York was definitely one of them and so I decided to focus on it. I planned to start analysing the relationship between COVID-19 cases/victims and some (key) urban variables such as the population size, population density, the overcrowding conditions, the commuting habits, the citizens working-profiles, the ethnicity, and some more. Data were (incredibly) already available online on the GitHub repository, making NY one of the first big cities in the world with full and daily updated data at several sub-urban scales. I decided to focus on ZIP Codes to have a very deep knowledge of every Boroughs (there are five in total), and I collected thousands of data. I developed both regression analysis and qualitative interpretations, but then in the end, after one year of work, my supervisors and I realized that those outcomes were too limited to "just one city". Moreover, because of that and of the first outcomes obtained, it was not possible to compare these results with other cities in which data were still lacking, and the results themselves were too weak (but also vague) to find solid arguments in the literature. I was then suggested to shift the attention exclusively on some urban *parameters that may have influenced the virus-diffusion and, importantly, to change the scale of the study, passing possibly to something comparable, more geographically extended, under a same administrative recognised level, and – unless some specificities – under the same political conditions. This request, together with the data-availability, the need to have a solid statistic model, and the ambition to offer a repeatable model (when the administrative level is shared), finally led me to base the case study on the relationship between COVID-19 behaviour and Population size and density at the US-metropolitan county level. In the United States, a county is an administrative (or political) subdivision of a state (belonging then to the second level of the Political divisions of the United States) that consists of a geographic region with specific boundaries and usually some level of governmental authority. As of 2020, there are currently 3.143 counties: some of them correspond simultaneously with a city, others are just referred to as a county. Considering the premises of the work and my interest in focusing more on the urbanized settings in which the virus spread, I finally adopted then a distinction (basing on the official definition provided by the US Office of Management and Budget (OMB)) between metropolitan and non-metropolitan areas, getting then a more restricted group of 923 metropolitan units. This definition, basing on areas of minimum 50,000 population, offered then a reasonable dimension in which starting back a new step of my thesis process, hopefully more structured, where many theoretical contributions can be integrated and re-discussed under this experience.*

As a consequence, after this focus-scale shift, many things in my work had to be changed, rearranged, omitted and redone. But it was an intense and deep process, worth doing, where I learnt a lot, not only from the literature and analysis but also from myself. Here is the work.

Introduction

The 11th of March 2020 is the date in which the General Director of the World Health Organization (WHO), Dr. Tedros Adhanom Ghebreyesus, declared as "a pandemic" the new infectious respiratory disease COVID-19, caused by the infection of novel coronavirus SARS-CoV-2 (Aldana et al., 2020). Indeed, the growth-rate of new cases, the increasing number of affected people and the rising number of deaths made the decision almost unavoidable, as numbers and facts have largely demonstrated afterwards. At the time of this writing (September 2022, as a last update and revision), according to "Our World in Data" database, the most updated number of world-wide infected cases correspond with more than 608 million people (and almost 6,51 million deaths), and the most affected countries are: US (95 million cases, 1,05 million deaths), India (44,5 million cases, 528.000 deaths), Brazil (34,5 million cases, 685.000 deaths), France (33,7 million cases, 151.000 deaths).

At that point in time, the US had one of the highest COVID-19 contagion rates and it still remains among the highest since long time. In fact, the US are among the first countries outside of China to report a huge number of positive COVID-19 cases and associated fatalities: the first case of Coronavirus was confirmed on the 1st of March 2020 in New York City, in a woman who had recently returned home to Manhattan from Iran some days before, on the 25th of February (West, 2020). Later on, genomic analyses highlighted that the disease was probably already circulating in the city from January, and most cases had links with Europe mainly, rather than Asia (Zimmer, 2020). By the end of May 2020, there were more than 1,5 million confirmed cases of COVID-19 in the US, and more than 100.000 related deaths.

In this unexpected condition of crisis, another confusing aspect is the identification of spatial elements which may have impacted on the COVID-19 circulation. From the neighbourhood scale to that of metropolitan counties, density and population size confirm themselves to be crucial and debated concepts in both theories and practice. However, as demonstrated also by an article of the New York Times, on April 23, 2020, sometimes the concept of density is confused with that of population urban population size (the above mentioned article was titled: "*America's Biggest Cities Were Already Losing Their Allure. What Happens Next?*"[2]).

[2] Accessible at: https://www.nytimes.com/2020/04/19/us/coronavirus-moving-city-future.html (Published April 19, 2020 - Updated April 23, 2020)

In fact, despite common fields, county density and metropolitan population size are distinct but also related concepts.

But in this context of COVID-19, too often these two elements are seen as predictors of the COVID-19 disease's course in the US, where the virus has spread widely from the early 2020. In fact, since the outbreak of COVID-19 and its diffusion across the globe, places with high urban density levels have appeared particularly under risk to some experts (Aldana et a., 2020; CNN, 2020; Coryne, 2020; Roy and Ghosh, 2020; Wong and Li, 2020; Jo et al., 2021; Sy et al., 2021). They tend to make a link between urban density (and sometimes also its population size) and its vulnerability, highlighting a quite obvious connection with the diffusion process followed by the virus. And despite behavioural policies of physical distancing and shelter in place, how far the virus can spread is often linked to population density and size. A popular argument is that high population size and/or density increase the vulnerability to epidemics because of the more frequent possibility of interpersonal contact. While some stand high density is a key factor, others claim there is no relationship (Barak et al. 2020; Carozzi, 2020; Hamidi et al., 2020; Pafka, 2020; Rajkumar, 2020). The same can be noticed for population size (Glaeser and Gottlieb, 2009; Boterman, 2020; Jamshidi et al., 2020; Siglier et al. 2020; Whittle and Diaz-Artiles, 2020). This contradictory approach highlights the lack of an appropriate framework in which trying to integrate the spread of COVID-19, the diffusion phenomena as a theory and geographical process, the complexity of urban systems and the specific spatial role, in this complex scenario, of two features as population size and density. Thus, after a deeper understanding and reconstruction of the theoretical background from which identify the key factors in place, then a new step is needed to identify the real relevant spatial components contributing to the virus spread at a certain scale. This current situation has a double consequence: on the side of academics, it shows a research area still in movement, implementable and poor in terms of updated materials and references; while on the other side of professionals, it limits the broader understanding of current and future changing conditions, occurring at urban level. Moreover, with specific attention on the case of pandemic, this lack influences the capacity of urbanism, urban planning, architecture and the built environment to address the health issue of pandemic with proper spatial solutions, in the light of new observations and "new daily praxis" in time of

COVID-19. Starting from this awareness, the present work aims to address these main gaps, through:

- The construction of a theoretical ground addressing COVID-19 phenomenon, the urban system, and the diffusion-theories;
- The explicit creation of a theoretical ground addressing, within this theoretical premise, density and population size features under the pandemic perspective in urban contexts;
- The identification of their role with the pandemic issue at theoretical level;
- The passage to a practical crisis experience to read and verify their role in time of pandemic urban crisis.

In order to shed further light on the topic and on these points, this thesis studies the role of density and population size on COVID-19 infection disease in a real study-area, so as to understand both direct and indirect impacts of these factors on the infection and mortality rates of 923 US metropolitan counties. Understandably, in this analysis, also other key contributing factors in the transmission process will be considered together with their role in their context of study.

Therefore, the integration of COVID-19 variables and context-variables at metropolitan county level can actually lead to the full understanding of an unexpected health emergency, capable to bring down secular contexts, socio-economic dynamics and cultural habits. This represents a relevant challenge for urban planners, designers, policymakers and academics in developing again urban science and operationalizing the findings. Thus, clarifying this deficiency can remarkably contribute to managing and improving urban conditions and functioning.

The novel coronavirus pandemic and the related global challenges addressing urbanized environments appear both an unexpected and interesting occasion to work in that direction. Indeed, at the time of writing and selecting the “stress to address”, COVID-19 exploded progressively worldwide, shutting down the engine of ideas and dynamics that drives urban centers everywhere and introducing unprecedented measures of social distancing, shelter in place, masks-wearing to limit the spread of the virus. Thus, the worldwide emergence of current (and future) pandemics highlights, among other things, the necessity to study and understand the role of the most popular and evident elements of urbanized systems and urbanized contexts, density and population size, to better deal with current (and new) pandemic diffusions (Lak et al., 2020). Moreover, since several other forces like climate change and human violation of natural habitats may rise the frequency of pandemics in the future, then deeper knowledge of their diffusion patterns and dynamics, their impacts, and basic preparation, response, and adaptation measures is required (Connolly et al., 2020).

Furthermore, there are evident reasons to sustain that our daily-contexts (together with our lives) will not be the same after COVID-19, but what about their forms and functioning?. The virus has raised the need to re-discuss the paradigm of planning, designing and managing the urbanized contexts (first among the others) guided by the concepts (already in place for other kinds of crisis) of resilience, adaptability, transformability and sustainability. Learning from the first lessons of the COVID-19 outbreak at a specific scale-level, this research aspires to clarify at least the real role of density and population size in this emergency, and then to point out some reflections and suggestions for planners, policy-makers and future research.

As expected, in terms of literature, to date most of urban systems literature facing disease is related to chronic health issues and less to infectious phenomenon. Moreover, the first COVID-19 research publications are focused on medical topics related to the diagnosis and cure of the disease (Harapan et al., 2020), and then to the possible “catalysers” which actively contributed to the virus-diffusion at different scales and within different contexts. However, since the very beginning of the pandemic outbreak, impacts of the virus especially on cities and their possible responses to it have also received relevant attention. Indeed, this crisis raises a lot of questions around the urban vulnerabilities that, mainly in terms of physical properties, may have favoured or may have limited the current and future spread of these infections with the purpose to make cities liveable, healthy and safe again. After all, we are physical beings and our cities have been designed for that, for moving, encountering, exploring and hosting all the human behaviours[3].

[3] These ones, when corresponding with events that gather a lot of people, may have also affected the spread of the virus, in a way that often rose the risk of transmission. In fact, as studied also by Harvey et al. (2021), Moritz et al. (2021), Ahammer et al. (2020), Klompas et al. (2020) and Mossong et al. (2008), the mass gathering for indoor events heavily contributed to the COVID-19 spread. That said however, this study will not directly focus on this kind of events, so as to remain on a broader scale and on more uniform and measurable variables.

That clarified, this thesis aims to: firstly, collect literature on density and population size, considered the two dimensions of modern cities of highest interest within this topic of disease affecting urban systems; secondly, to collect data about these two dimensions, supported also by other urban features, and about the COVID-19 features that better describe its dynamics at a certain described scale; thirdly, with focus on the pandemic crisis of COVID-19 in the 923 US Metropolitan counties, to understand the role of density and population size in favouring or limiting the virus contagion (also in comparison with other county-variables); fourthly, to highlight what the analysis-results suggest about new steps needed in planning, research and urban policies. As previously mentioned, the choice to focus on the US county level derives from a methodological and structural need of having a broader and comparable scale of observation, sharing a common administrative level sharing the same level of policies, developing a solid statistical model, collecting uniform and updated data, while offering a repeatable (calculation) model (repeatable for instance, in case of available and constantly updated data one day for: the Italian metropolitan areas or cities, the French cities, etc.). Moreover, the specific choice to focus then – among the 3.143 US counties – only on the so-called "Metropolitan" ones (923 units) has to do with the interest in highly populated areas where the concentration of people and activities is usually higher. In the United States, the metropolitan counties are defined by the US Office of Management and Budget (OMB) and used by the Census Bureau and other federal government agencies for statistical reasons (Nussle, 2008). Metro and non-metro status was defined by the Office of Management and Budget (OMB) in February 2013. Urban/rural classification type is based on the 2013 National Center for Health Statistics Urban-Rural Classification Scheme for Counties. In terms of statistics and space, a metropolitan statistical area (MSA) is a geographical region with a relatively high population density at its core and close economic ties throughout that area. According to the "2020 Standards for Delineating Core Based Statistical Areas", the general concept from which the distinction between Metropolitan (and micropolitan or rural) originates is a core based statistical area (CBSA) containing a large population nucleus, or urban area, and adjacent communities having a high degree of integration with that nucleus. These premises and definitions made, despite specific differences on the field, the spatial base on which starting the analysis more structured.

Although the overmentioned ambitions, it is already clear that the current global crisis posed by COVID-19 at all levels will take a long time to develop new models that can be adopted also in architecture and urban planning to reduce the risks arising from a similar pandemic. In this sense, another interesting point to deepen will refer to the so-called "**lessons learnt**" from the case study and how they can contribute to develop further research on "the role of density and population size in dealing with pandemic crisis", having clear that the diffusion process finds a fertile ground in the urban-system dynamics. In fact, once at the end of the work, it will be central to firstly recognize the main lessons learnt from the disease experience of US counties and, secondly, to understand their contribution not only to this research goals but also to the more general research context that is now activating on the topic. As already mentioned, one of the main ambitions for which "understanding the role of these population features" relates to the deep need and wish of people to feel, in any time of crisis, comfortable, welcome and safe in the cities they live. Unfortunately, this coronavirus crisis has affected this perception and condition in several urban environments, in a way that the relationship with spaces, especially when other persons are present, has changed. From this point of view, also other elements of urban environment have a role, especially in providing clear data on how forms and functions influence the virus-diffusion and thus alter also the way urban space is perceived and seen by its citizens. These findings can support the phases of crisis, recovery and adaptive transformation of cities, indicating also the most effective properties to put in place in order to be more active, ready and resilient to this and future pandemics.

1.1 Research topic and statement

When this work started in late 2018, it focused on the growing debate on the relationship between cities (as systems) and change. The early idea of the thesis intended to propose a merging attempt of different disciplines, facing specifically the condition of change and its related consequences (either positive or negative). This experimental approach has its roots in the increasing awareness of the uncertainties characterising the Urban Era we are already living.

Developing the work in this direction, after the initial definition of the theoretical framework and the progressive passage on a specific phenomenon of crisis to observe or a specific case study, something unexpected came up in the early 2020, leaving an indelible mark on the development of this research: the pandemic crisis of COVID-19 paralyzed the world, with heavy consequences never seen before and a rapid spread in cities. This shock became then an interesting crisis-experience for this thesis to understand the role of urban forms in the spread of, the containment of and the reorganization from the virus. Furthermore, early attention on infectious diseases and pandemics from the perspective of urban disciplines appears innovative and worth. However, as we observed from reality, the design and structure of cities and how they have been planned and inhabited can often accelerate the problem of infectious diseases. In this regard, the effort to introduce an in-depth study on the role of density and population size in time of pandemic might contribute to the development of a new research frontier for merging spatial-principles, new urban concepts and public health studies, providing both theoretical inputs for further debate and practical ideas to increase urban preparedness. It must be said however that to date, some literature addressing the dynamics of diffusion has already been published by some geographers, starting from the pioneering work of Torsten Hägerstrand. The importance of his thesis (Hägerstrand - PhD dissertation, 1952) refers to the definition of the "diffusion" as a very basic and crucial geographical process: in fact, he stated that no matter what the phenomenon being diffused might be, one may see it in the framework of a larger world-wide process of spatial and temporal diffusion (see more in Chapter 2). Thus, there is already a background to consider diffusion as a "chronological process" (Sörlin, 2020) where the knowledge of the spatial patterns within the so-called "contact-network" can support the prediction of spatial patterns themselves.

Therefore, once clarified the current state of research on the topic and then integrated with new findings, this unexplored research field might lead to some scientific results worth mentioning in the contexts of academia and spatial-planning exercise, while at the same time, might reduce the distance between planning and concepts like resilience, adaptation and transformation.

As evidences state, it must be said that today there is no doubt that urban contexts are home for more than 54% of world population and since about the 67% of world population is projected to live in cities by 2050 (UNDESA, 2014; UNHABITAT, 2016). 21st century humanity will increasingly be urban (UN, 2014) and will progressively face crisis and uncertainty (Biggs et al., 2011). In 2009, urban population outnumbered rural residents for the first time in human history, initiating officially the so-called "Metropolitan Century" (OECD, 2015). Urban transformations are then reasonably and increasingly expected, through both new urbanities and renovations in historical cities. However, if changes in urban contexts have always occurred, the current magnitude and speed of change are totally new, unexpected, sometimes unpredictable and difficult to manage. Needless to say, also the likelihood of new pandemic plagues is constantly rising, partly also because human race is continuing to urbanise (Madhav et al., 2017). In this context, it is pretty evident that the COVID-19 outbreak is hurling down the cities worldwide to a complete lockdown situation and stand-by condition never seen in Contemporary times. Moreover, this widespread experience is adversely influencing several countries in the world, regardless of their income and commitment to integrate health issues in the urban development and in their SDGs Agendas (Lak et al., 2020).

Logically, these phenomena highlight the vulnerability of our cities to unexpected change: from the several effects of anthropic behaviours, economic fluctuations, pandemics, political decisions, to natural disturbances, slow variables and climate change impacts. All over the world, the fear is that a lack of holistic and forward-looking strategies will lead to rising inequalities, isolation, fragmentation and deeper gap between rich and poor, safe and unsafe, secure and risky, and so on. And this becomes even more evident when dealing with pandemic threat, as it may turn out to be a long-term or chronic problem, following theoretical but also very practical patterns, where urban systems and spatial planning need to find proper ways to adapt and, sometimes, evolve.

For these reasons then, two key aspects of urban contexts will be addressed, together with other context-variables, in order to discuss possible interdependencies between urban elements and pandemic-crisis diffusion and then to highlight possible new perspectives to support the urban systems to recover or to change in safer and longer-term direction.

1.2 Research structure

This section explores the key pillars of the work and clarifies the research aims, questions, background and boundaries.

1.2.1 Research objectives and questions

The prime purpose of this study is to understand how the two central features of urban population – size and density – affected the on-going COVID-19 pandemic. More specifically, the ambition is to understand "their role in dealing with the pandemic-crisis experience of COVID-19". In fact, as the section on the literature review will better describe, since the early outbreak of the virus, a growing debate blaming (mainly) density and population size has quickly risen, making the need of deeper analysis increasingly valuable.

To better address this goal, the thesis will try to answer to this first general research question:

> "COVID-19 pandemic experience at the US Metropolitan County level: what is the role of density and population size?

This question will be horizontally addressed along the whole work, partly through theoretical findings, and partly with practical samples. Moreover, from this overarching aim, a number of more specific questions derives as follows:

a. Within this pandemic experience, are there any "propagators" or "promoters" of the phenomenon (especially after the case study analysis and in comparison with the thesis-argument)?
b. According to the data observation and results of this study, is it possible to find any urban features that may mainstream the health-criteria into the spatial planning and design field?
c. Which urban properties have been more exposed to the diffusion spatial process of COVID-19? Will the temporary transformations observed along this crisis introduce more permanent changes in the future?

Considering the magnitude of the topic, there will not be a specific section where these questions are deepened, but rather several contributions that, once arrived at the conclusion, built-up argued and structured answers.

As far as the existing studies did not exclude the weight that also many indirect factors could partly cover in magnifying or diminishing the actual impact of COVID-19, this thesis study would necessarily include additional variables, to clearly distinguish the net impact of density and size on COVID-19 growth. In parallel to that, the study considers also whether or not a county is "metro", since this condition could to some extent influence the roles of population size and density in dealing with the pandemic.

This research has also the potential to provide lessons for planners on how urbanization and socio-economic condition might influence the crisis-management and the public health cost of the increase of population size and density at the scale of a county in United States.

More deeply, this thesis can potentially integrate planning topics and the direct experience of a crisis-phenomena, not only in theory but also addressing realistic data. In this sense, understanding the increasing need to incorporate explicitly the element of change and the dimension of time in the planning and intervention of cities becomes crucial, and good inputs can also be taken from the diffusion-theory, fundamental in geography, suggesting the concept of constant change (Hägerstrand, 1982). Indeed, as stated by Samuelsson et al. (2020) in a paper developed in time of COVID-19, we have to learn a first lesson from this global and unexpected experience: cities, no matter where they are, need to accept that 21st century is offering and will progressively offer new crisis regimes of the Anthropocene as a "new reality" to be accepted and to co-exist with.

However to date, despite the large use of resilience theories applied to planning and of sustainability principles to build better urban environments, few papers have been published about how the urban physical space will be able to deal with COVID-19 shock through this perspective: to date, despite the significant consequences of infection transmission in cities and urban contexts, limited research and material exists on how such an adverse experience will lead to absorption, recovery or adaptation, especially in light of evidences about COVID-19 relationship with density and population size. Thus, whether on one hand, few academics underline that planning features and crisis experience should be tackled together, especially in this COVID-19 emergency; on the other hand, the traditional literature and the international community of policy-makers and professionals are continuing to foster the employment of sectoral ad-hoc approach.

Therefore, justified by the need to deepen more these two dimensions and to test the validity of two main population features (analysed with others) to support cities in dealing with this threatening pandemic scenario (that may re-occur in the future), the present study is carried out by applying the following steps:

1. In a first stage, the thesis will try to collect, integrate and understand the general literature on urban systems and diffusion theory, so as to favour the successive theoretical zoom on density and population size in time of pandemic, since they represent two undeniable characteristics of any urban space which firstly enter in contact (with pros and cons) with any kind of shocks;

2. In a second stage, the work will try to collect data based on a reliable and stable case study (especially in statistical terms), on which building the quantitative analysis;

3. In a third step, the thesis will critically interpret the analysis outputs, demonstrating the role of density and population size in dealing with the condition of crisis and uncertainty provoked by the rapid spread of an unknown infection, and thus what can be extrapolated for planning implications and further research;

4. In a final step, the work will try to indicate what the results contain, identify the opportunities that can be taken in the planning field, and the lessons that can be learnt from this global plague at the urban level, also considering other possible emergency scenarios in the future and a more complex global scenario of change (ex: climate change, energy and water scarcity, poverty inequalities, economic crisis, and so on) (Banai, 2020).

The proposed process and its tentative translation in practical understating of urban contexts we usually live, will possibly lead to a progressive integration of concepts like resilience in urban morphology patterns, and thus offer another interesting perspective to understand cities affected by crisis. These principles will possibly develop a new understanding of cities of tomorrow, highlighting both physical and non-physical aspects in place (Lak et al., 2020).

1.2.2 Setting the scene (for the present study)

A new Chinese coronavirus, a cousin of the SARS virus,
has infected hundreds since the outbreak began in Wuhan, China, in December.
Scientist Leo Poon, who first decoded the virus, thinks it likely started in an animal and spread to humans. "What we know is it causes pneumonia and then doesn't respond to antibiotic treatment, which is not surprising, but then in terms of mortality, SARS kills 10% of the individuals,"
Poon, a virologist at the School of Public Health at The University of Hong Kong, said.

(Jen Christensen and Meera Senthilingam, CNN – January 20, 2020)

Back on the 31st of December 2019, the Chinese government confirmed that health authorities treated dozens of cases of pneumonia of "unknow cause" (NYT by Taylor, 2021). After several days, already in January 2020, Chinese researchers identified a new virus with high infection levels. At that time however, evidence about the virus spread by humans was still missing, and China's official health channels stated that they were monitoring the situation in order to prevent a more severe outbreak.

But as time passed, on January 11, the Chinese media informed about the first known death provoked by the virus that, in turn, had infected dozens of persons. The 61-year-victim was a systematic customer at Wuhan-market. After this news, as almost expected, other counties confirmed their own cases: among them, on January 21, the United States confirmed the first case in Washington State, where a young-30s-man developed symptoms once back from a trip exactly to Wuhan.

After some days of increasing cases (and deaths) confirmations among Japan, Thailand, Taiwan, South Korea and the United States, and of the first adoption by the Chinese authorities of partial lockdown measures, on January 30 the W.H.O. declared a global health emergency. Among thousands of new cases worldwide, the American first reaction saw a suspension of first international travels to China. With rising frustration of having ignored the first denounces of coronavirus by the Chinese doctor Dr. Li Wenliang (who then died after having contracted the virus), on February 11 the W.H.O. proposed an official name for the virus: COVID-19.

Meanwhile, Europe saw its first major surge as the number of recorded cases in Italy grew incredibly high from the end of February 2020. Iran and Latin America started immediately after to report their cases, followed by the first reported death in the United States on February 29 (a patient close to Seattle was believed to be the first COVID-19 victim in the US at that time). An intense sign of the occurring global emergency came publicly on March 8, when Giuseppe Conte, the Italian Prime Minister of the time, signed a decree ordering travel restrictions on the entire Lombardy region and 14 other provinces, limiting the movements of more than 10 million citizens living in the northern part of the Country. Surprisingly, the day after (March 9, 2020) he announced that the whole of Italy was on lockdown.

The rapid extent of this emergency was so obvious that on March 11, the W.H.O. declared the novel coronavirus outbreak to be a "pandemic". And then… what happened next is (sadly) very well known as the diffusion of this virus did not stop and, on the contrary, became local and local highlighting, among other socio-economic and political disparities, great social inequalities often within the same spatial context.

But what is a Coronavirus? According to the Jhon Hopkins Medicine (last update on July 29, 2022), "*Coronaviruses are a type of virus. There are many different kinds, and some cause disease. A coronavirus identified in 2019, SARS-CoV-2, has caused a pandemic of respiratory illness, called COVID-19.*" COVID-19 can become severe and, along the global pandemic emergency, has provoked millions of deaths as well as long-term health issues in some patients who have survived to the infection. Despite at the beginning there was uncertainty about its diffusion, today it is clear that coronavirus proliferates through virus particles and drops released into the air from an infected person (through his/her breaths, talks, coughs, sneezes, laughs, and so on). Tiny infectious units can remain in the air and then cause an accumulation in indoor places, especially when many persons are gathering, and the ventilation is poor. This is the reason why it became soon essential to prevent COVID-19 to wear masks, sanitize hands frequently and apply physical distancing.

The infected people usually experience mild/modest respiratory illness and recover without the need for medical attention. However, in some cases (more frequent among vulnerable categories), the infection becomes serious and requires special treatment. In fact, studies and observations have clarified that the elders and those with cardiovascular or respiratory disease, diabetes, or cancer are more likely to develop grave symptoms. In any case however, W.H.O. and other relevant research-centers clarified that anyone could get infected by COVID-19 and then "*become seriously ill or die at any age*"[4] (W.H.O., 2020).

From this important premise, which helps to better frame the interest and the extension of this topic, it can be said that this thesis is particularly interesting because, first of all, has to do with an unexpected crisis, challenging the whole Anthropocene world. Not only, because of an interest in urbanised settings and related dynamics, the work is also curious as it tries to understand the role of two characteristics (population size and density), among the more typical urban features of our contemporary globalized time, in the COVID-19 diffusion. The importance to understand this relationship is crucial to understand the function of cities (today and in the future), the future tasks in the urban planning field and design, but also in the progress of the Sustainable Development Goals (SDG). In fact, in the effort of enhancing sustainability in territorial and urban systems according to the sustainable development agenda, this pandemic can represent both a huge challenge and a great opportunity for achieving the 2030 Agenda and its Goals since Covid-19 highlights, among the rest, the importance of solving sustainability challenges, giving new priorities while rebalancing some global issues and growing perspectives (van Zanten et al., 2020).

In order to fulfil these ambitions, the thesis recognises the importance of working with both existing (and progressively available) literature on the topics of infection diseases, urban planning and complexity, and practical pandemic experience. This approach, better framed, corresponds with an **exploratory sequential mixed methods**, where qualitative and quantitative data and analysis are combined through a sequence of phases (Creswell and Plano Clark, 2018). Although a deeper explanation of this methodological aspect will be addressed in Chapter 3, here it is worth saying that while the first part of the work focuses on the collection and analysis of quantitative data, the following second one can correspond with

[4] W.H.O., Coronavirus disease (COVID-19) – Overview. (Last access on August 10, 2022: https://www.who.int/health-topics/coronavirus#tab=tab_1)

several forms of data collection. Therefore, it means that the qualitative part provides critical issues to develop specific research topics for the quantitative section. This method can actually lead to deeper knowledge of the problem and to more reliable perspectives, directly coming from the case study analysis and understanding. To achieve that, after a deep theoretical study, the thesis works with data from one of the most affected places in the world, the United States. This apparently strange decision (why, for instance, shouldn't this thesis have worked with Italian data or within the European context?) has actually to do with the quality of data itself, with specific attention to when (and how) the data-collection process started in 2020. Indeed, from the very beginning (January 2020) the US, thanks (mainly) to The Johns Hopkins Coronavirus Resource Center, The New York Times, The Economist, and the U.S. Centers for Disease Control and Prevention (CDC), developed a full and constantly updated data-collection open to the public. These sources proposed different kinds of data under the categories of COVID-19 cases, deaths, tested and positive people, hospitalised (and in the future, vaccinated) and in the forms of absolute numbers, cumulative and incremental data collection available in tables, graphics, and maps. Moreover, instead of offering just individual-level records, these data are usually processed into specific measurements, for instance, the 7-day average increase in cases, per capita deaths, cases every 100.000 inhabitants, and so on. Together with cases and deaths then, US data offered as soon as it became possible, data also about tests performed, the (test) positivity rate (the percentage of tests having a positive result), the number of vaccines delivered (once that they became available), and so on. These data were made available on the GitHub database, which contains all data, mapping, and analysis from the Johns Hopkins University Center for Systems Science and Engineering (JHU CSSE) (clearly collected and easily downloadable) and provides them to the public for educational and academic research purposes. In parallel with the early US data-aggregation managed by the U.S. Centers for Disease Control and Prevention (CDC), in Europe the European Centre for Disease Prevention and Control (ECDC) started also to aggregate data from their own constituencies. Considering their previous efforts to harmonize data systems, these two organizations often have more comparable data than other fonts, but even so the comparability has represented an issue with COVID-19, making the comparison between US and EU data complicated also for this work.

Considering in fact the importance of proposing a stable, solid, repeatable and implementable case study, the decision to work on a US case study actually made the whole analysis more doable, accessible and clear, as the US Metropolitan Counties crisis experience of COVID-19 refers to a level of study that shares, at least, the same administrative, geographical and statistical definition. As better explained in Chapter 3, the "case study research approach" in urban design research is a typology of empirical research strategy which can be often found in urban and architectural works (Groat and Wang, 2013). Through profound investigation of a series of situations in real life contexts, CSR allows to create knowledge on a system. In this case, as previously clarified, the ambition is to shed light on the role of population size and density on the COVID-19 spread in urban settings. In this work, the urban set corresponds with the US Metropolitan Counties (923 units) which are the geographic unit for which consistent virus infection and death data are publicly and easily available. Moreover, their data are less likely to suffer from aggregation bias than an analysis at the state or metropolitan area level would (Hamidi et al., 2020).

Although the spatial scale of analysis is not very detailed (and the reasons are mainly related to the progressive loss of data-quality when passing to metropolitan areas, cities or neighbourhoods), in this work the US metropolitan counties correctly correspond with the "urban concept" proposed by the literature on diffusion and infection-analysis, that sees in dense areas ("dense" especially in terms of network, dynamics, material and immaterial exchange) and a higher probability of contagion (Glaeser, 2011; Kao et al., 2012; Garrett, 2010; Haggett and Cliff, 2006), but also with the "urban classification" adopted by the Bureau of the Census (2021)[5]. With reference to both research areas, two elements can be addressed to deepen this research: density (especially in the diffusion theory and infection-studies) and population size (the first element considered by the Bureau then distinguishing "urban" from "rural"). Not only, as the first evidence on COVID-19 states (sometimes a bit confusingly) (Bliss and Capps, 2020; CNN, May 2, 2020; Jamshidi et al. 2020; Kimmelman, 2020; Klaus, 2020; The New York Times, April 23, 2020; Whittle & Diaz-Artiles 2020;), there may be a relationship between denser areas and the spread of the virus. And this condition has only

[5] The US Bureau of the Census defines an "urban area" as built-up area with a population of 50,000 or more. It comprises one or more places—central place(s)—and the adjacent densely settled surrounding area—urban fringe—consisting of other places and nonplace territory. (Source: https://www2.census.gov/geo/pdfs/reference/GARM/Ch12GARM.pdf, last access: August 2022).

partly to do with the typical "population density" feature but also with the other typical elements characterising the highly populated urban contexts and, according to this line of research, favouring a virus-diffusion ground: several mobility patterns and commuting opportunities, economic activities, social aggregation activities, socioeconomic disparities (Quinn and Kumar, 2014), open space presence, cultural events, tourism (Alirol et al., 2011) and so on. These elements, while summarizing the urban concept, can here be found at the metropolitan county scale, for which the United States offers a complete, stable and updated data-collection.

1.2.3 Research boundaries

In the context of this work, it is necessary to define a **suitable area of research**. It is firstly fundamental to understand **the kind of disturbance to address, the stage of the disaster-management-cycle to work in, and for what purpose (s)**.

This key passage will set a first level of boundaries which will guide the definition of the other answers and steps. Subsequently, the process will start introducing an experience of global crisis, to be read through some urban features (density and population size), which may influence the dynamics and impacts of the crisis itself. This passage is interesting not only to recognize the role covered by these features, but also to understand the weight of other urban features in place. The complex framework coming out from this analysis will then bring to the context of resilience science, **whose principles** can be integrated into the planning field experiencing crisis-phenomenon. This wide research framework needs then some boundaries to better set the working field.

According to the goals of this study, clear decisions must be taken on what can be in and what remains outside the study-context, as the topic and the possible contributors look very wide and potentially dispersive. Especially when the work starts from a very specific area of interest, limited here to two spatial features to be linked with COVID-19 diffusion in urban settings, and then associates these findings to broader concepts, as resilience, complexity, adaptation and so on. The early choice of focusing on the COVID-19 crisis affecting cities

globally, rather than other kinds of changes, implies then several decisions in this work, excluding others. Indeed, over the last decades, lots of studies have been performed on the relationships between urban planning, architecture, design and the goal of health and well-being in vulnerable communities affected by hazards, natural or climatic disasters and chronic diseases. Conversely, **not enough has been developed on infectious diseases and pandemics from the perspective of urban planning**, architecture and design, with the ambition to open the topic to new research frameworks.
Therefore, the focus on COVID-19 has the powerful effect to remind anyone who still believes that infectious diseases were history or rather restricted to poor communities, that our "incubator-cities" must be prepared to resist, adapt and probably transform to this kind of crisis also in the 21st century. Undoubtedly, it would be senseless to ignore the presence of several other risks stressing cities today and in the future, but within this work, this boundary is useful to focus on a specific topic of common interest.

From the very beginning, it became important to understand **how the tensions introduced by COVID-19 disturbance were influenced by two central features of our time** (population size and density). However, being these features part of a more complex socio-economic context (in this case corresponding to the 923 US Metropolitan Counties), the data collection was immediately integrated with other elements, already in place, and potentially linked with the virus as well (as growing literature suggests).

Unquestionably, this represents an important step to start giving some practical contexts for reading and interpreting the virus behaviour, to move further to higher levels of reflection.

In fact, as better explained in Chapter 2, under this context of crisis, the diffusion-theory introduced by the geographer Torsten Hägerstrand in the middle of the 20th century, has now to do with the movement of a virus through space and time, following the (original) "idea of process" and the drawing of a pattern. These footprints, in an urban context of growing complexity, require the introduction of resilience paradigm and adaptation concept, as growing discourses under the wider urban-sustainability umbrella. In this scenario, they have in fact the potential to constitute a **promising theoretical "toolbox"** to understand complex-adaptive systems and enhance the quality of life in cities (Marcus and Colding, 2014;

Samuelsson et al., 2019). Michel Juffé comments on this situation stating that resilience is too often used as a "qualifier applied to anything" (2013). The concept itself of "resilient city" is quite difficult to describe as it is becoming so multi-faceted and all-encompassing. However, in this complicated context it is necessary to focus on the outcomes of the quantitative analysis and then move to more open reflection on how resilience principles embedded in adaptation cycles will cope with the new scenarios of the post-pandemic Era.
Although a deeper explanation on resilience cycle will be provided in the next Chapter, it is important to clarify that any changing-phenomenon occurring in an urban system crosses several phases. Not only: cities, as dynamic entities, contain structures in constant evolution. This permanent movement increases the complexity of studying the role of urban properties (as density and population size) and highlights the significance of considering the **resilience adaptive-cycle**.

This framework emphasises the need of paying attention to urban dynamics over time and across space, considering also the different phases of the adaptive cycle. Indeed, it consists of four distinct steps: the first two, named "**Exploitation**" (r phase) and "**Conservation**" (k phase) which form the "front loop"; and the second two, named "**Release**" (Ω phase) and "**Reorganization**" (α phase) which form the "back loop" of the cycle. According to the phase, resilience is high or low, the system is more or less simple, the connections between system components and actors are more or less tight, efficient and specialized, the system is more or less stable, innovative and rigid.

In this model, a general metaphor is proposed with a set of possible different trajectories. Across the four phases, there is a constant shift between stabilizing and destabilizing powers, but also between rigidity and flexibility. Therefore, in the context of this research it will be important to focus on a co-ordinated activity in "renewal and innovation" that is capable to discuss about and include changes that turn out to be necessary for the future, even when they are not immediate nor clearly observable especially in the context of the two spatial features under observation.

Conclusively, this passage represents an important step in the partially explored approach of **reading COVID-19 phenomenon occurring in the spatial dimension of cities through resilience perspective**, but also in making the findings informative and supportive in future built-environment interventions. Because of this ambition, the work, starting from the quantitative outcomes of the regression analysis that will be provided, addresses the capacity of socio-ecological systems to **change, adapt or transform** in face of strains and stresses, rather than facing change with a "return to normality and previous state" (Carpenter et al., 2005; Simmie and Martin, 2010; Davoudi, 2012) in line with the *bouncing forward perspective* (see Chapter 2).

1.3 Research organisation and disposition

In light of what mentioned and addressed above, in this section it is important to present and organize the work according to a structured logic that, aware of the research gaps, proposes a methodology to apply along the work and, when necessary, to implement if needed.

In this sense, it must be said that the research follows a sort of "progressively-deep approach", where initially only theories are analysed separately, then integrated, and lastly joined with a practical case of disturbance (Figure 1).

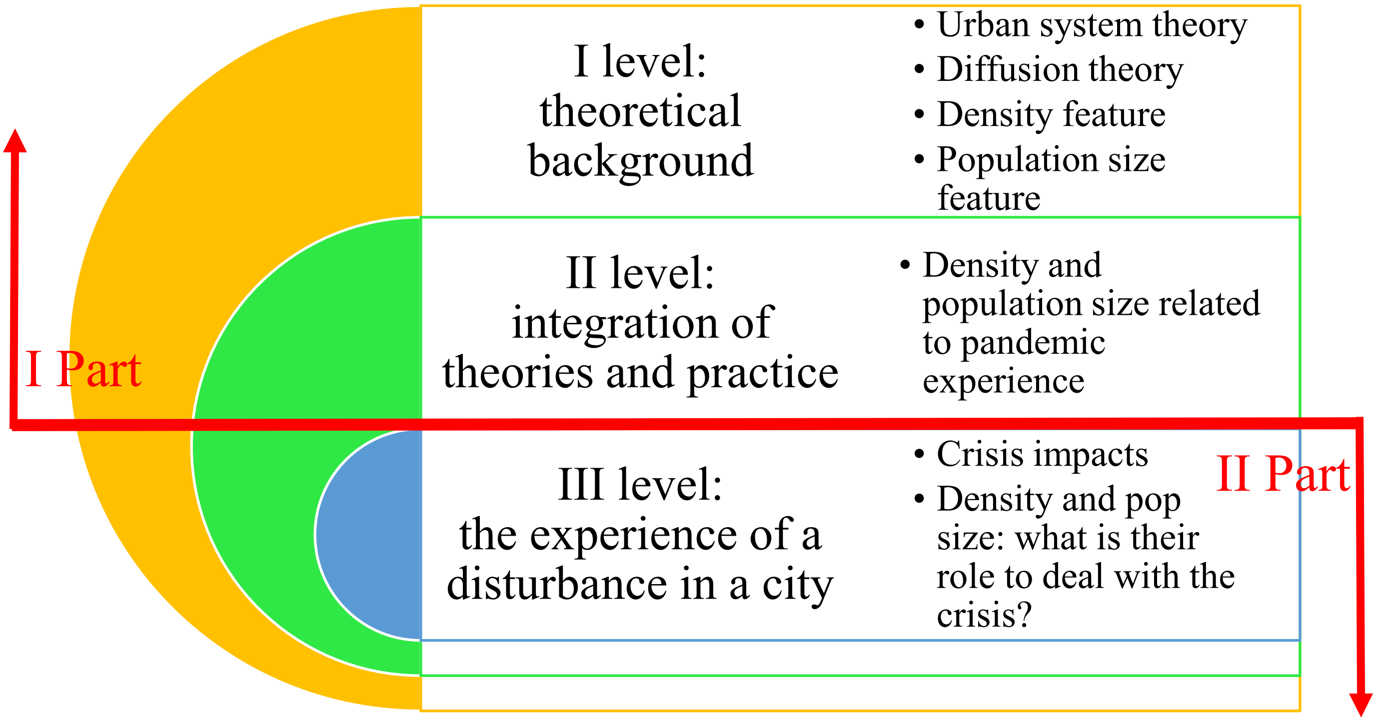

Figure 1 - Organizing the work according to three levels of analysis. From a broader theoretical view to a more focused understanding of a specific disturbance-experience (Author's elaboration, 2020).

These ambitions will be operationalized along the thesis as a result of a sequential process:

- Initially, a focused **literature review** on the urbanities as systems and the diffusion-theory will be provided, in order to frame the two concepts addressed in the work. For this reason, a subsequent passage will try to consolidate and then combine the theoretical knowledge on density and population size elements. More specifically, the emphasis will turn on how the diffusion of the virus is impacted by these two features, belonging to urban complex scenarios. This step is crucial to understand the consistency of the two concepts in the COVID-19 crisis, but also in relation to the literature on urban systems and diffusion-theory.
- Successively, a **theoretical framework** combining density and population size in dealing with the pandemic crisis will be presented. This passage allows to recognize the possible combination of the two topics, also considering the framework of complex-systems and resilience-perspective.
- Consecutively, a **practical application** of this interpretation will be provided through the analysis of the new coronavirus pandemic crisis in the metropolitan county context of the US. The reasons behind this scale and geographical choice have already been explained, but it can be added here that these counties offer a good combination of, on one side, highly population size-numbers (being administrative units with more than 50'000 inhabitants) and, on the other, a mix of denser areas within the units-themselves (often corresponding with the central city of the Metropolitan County);
- The observed implications on the urban built environment will highlight pressures on the existing system and will probably also require new praxis and approaches. In this sense, the massive urbanization of last decades and the related properties of built environment will be critically read in order to understand not only the link between the spatial characteristics and the virus diffusion, but also the physical properties that may limit any diseases spread in the urban future and thus, may support the development of high life-levels.
- Finally, a **conclusive overview** on the role of density and population size in dealing with the pandemic experience of COVID-19 will be developed, in order to close the thesis with an increased awareness of their functions and of their implications for planning. More detailed words cannot be spent yet on this issue as a lot of reflections will emerge only after the literature review and practical analysis of the local context.

In a nutshell, it should be noted that these passages are not independent from each other but tightly related: from one came the other under a logical subsequence of understanding the topic deeper and deeper.

Because of the substance of the topics addressed, it may be said that the work is basically divided into two main parts (Figure 1 – red line): a first part for the theoretical background where the concepts guiding the reading and understanding of COVID-19 spatial impact are deepened; and a second more practical section where the legitimacy of this interest is "tested" through the pandemic crisis of COVID-19.

This research can then be considered a pathway made of several segments and tasks, such as the identification of the research goal, the literature review of both wide sources and also of very small niches, the identification of the research gap both at general level and at specific level of the crisis-experience selected, the definition of the theoretical and analytical framework, the identification of links with the COVID-19 disease, the critical analysis of the results starting from the outcomes of the case study, and the main findings and limitations.

First, the research begins with literature reviews on the two main physical features of interest, density and population size, in order the collect the most recent debates on their meaning and role in the outbreak of the pandemic. These first steps are propaedeutic for:

- **defining the theoretical framework** in which developing this research,
- **discovering the research and theoretical gaps**, and
- **building an analytical approach** useful not only to integrate the theoretical field with the practical case study crisis-experience, but also to explore later the crisis-phenomena analysed.

From this outset, the research passes to focus on a specific crisis experience, such as the COVID-19 phenomenon and to the state-of-the-art in terms of literature and first highlights at the metropolitan county level. The "stand-by" of cities and broader urban environments provoked by the complete lock-down situation stresses the need to understand the role of the "functions" and the "forms" taken by the built-environment in the spread of pandemic and the possible scenarios for the future of urban space in the Global North.

The aim is to investigate on the role of the main population features in dealing with the crisis, outlining then possible planning implications and new approaches capable to face, adapt to and take opportunity from the pandemic crisis, in order also to conduct some critical comparisons with the theoretical background and to, eventually, validate the analytical line. Therefore, the research analytical approach was created *in itinere*. It began as the outcome of the first literature reviews and was then refined based on the first analytical observations of the pandemic crisis and on further literature reviews on the topic. This first phase considers also, in preparation for the final implications and suggestions for planning, to integrate possible conceptual perspectives, like complex and system theories, as well as socio-ecological resilience. This means also that a further check on the literature review needs to be done progressively as a complement to the previous one, whose focus was broader and related to the heterogeneous literature on the topics. Moreover, a first attempt of literature review was conducted on the issue of how COVID-19 is challenging the characteristics of our physical urban space, as academia and planners need to be concerned about this kind of crisis-phenomena as well, and start thinking about the impacts of the virus on shape and functions of our places. Due to its early nature, this further dive in the literature is undoubtedly implementable.

The findings will try to critically discuss those population and spatial properties immediately called into question in the light of what the Coronavirus crisis highlights from the urban liveability perspective. Indeed, some urban properties may have amplified the virus-diffusion while others might have limited it. Needless to say, some characteristics should be totally re-discussed after this work, while others should be more considered in the spatial-making process.

A methodological framework organized in this way should allow a progressive and deeper understanding of the relationships between density/population size and the spread of a crisis, and the subsequent need to deepen this issue at a practical level also to face the unexpected disturb of COVID-19 (see Chapter 3). As previously presented, the research goal and questions will guide this “zoom-in” process, facilitating the empirical observation of the “role of density and population size in facing COVID-19” topic, and then finding out some first structured and argued outcomes.

1.4 Expected results and limitations

Considering that the thesis is mainly developed on two sides (a very theoretical one and a more "experience-oriented" one), the **expected outcomes** will go in the direction to build first a new theoretical background, and secondly to clarify the role of density and population size in dealing with the crisis-management of COVID-19 at the local level. While the theoretical outcomes represent an important step for developing the growing field of urban literature around the urban issues involved in any crisis phenomena, the second step highlights possible ways to reflect on how Coronavirus crisis may fundamentally challenge our urban spaces and the traditional characteristics they have. In general, the research aims to offer a new perspective to expand the discourse on Coronavirus impacts from a still poorly explored field and to contribute to the discussion of its effects on urban-environment. And beyond this ambition, with the outcomes of this work, it is hoped to **contribute to the development of a required and encouraged multidisciplinary and integrated approach to urban science** (Olazabal et al., 2012), where the element of crisis is progressively integrated in the urban-system planning and understanding. This effort can inspire new streams of research, while representing an opportunity for closer and increasing collaborations between different roles and disciplines, one for all the public health science.
More specifically, the research has the ambition to:

- Provide new insights on the theoretical background related to the integration of urban environment properties and pandemic crisis;

- Identify the properties-role thanks firstly to the literature-support and critical review;

- Understand the importance of adapting and transforming urban-space in response to crisis, here in particular, to the new coronavirus outbreak;

- Underline the lack of literature and studies about infectious diseases in cities, as in these last decades too much attention has been given to chronic diseases, hazards and disasters;

- Highlight possible suggestions for spatial and urban planning in a post COVID-19 era, where more attention to crisis will be probably required to all contemporary and planned contexts.

These outcomes, along with more specific suggestions distilled from each chapter, are expected to **improve the usability of this research field** in future applications and studies.

This research shows also some limitations. In this sense, it is important to underline that the work is limited to a selection of the built environment properties and does not take directly in consideration the whole dimensions interacting at the urban level. That said, however, it is undoubtedly recognized that other fields like sociology, economy, environment, planning regulations and polices are central to determine the functioning of cities and operate an essential role in understanding their dynamics during crisis, as well as the spread of diseases. In this sense, it is evident that many city elements and dimensions take actively part in this stressing process, even though they are not central in this thesis. The case study analysis will represent a crucial point in this sense and will probably clarify a lot of aspects that in theory appear too wide.

Another limitation of this work relates to the temporal dimension observed. In fact, urban contexts usually see temporal transformations of their environments, functions and morphology over centuries, not years or few months. Although such a study would be a very interesting and precious analysis, under the current context of COVID-19 it is not possible (yet) to "conclude it" as the dynamics are still on-going and data collection is continuously evolving and increasing. Especially when reflecting on the huge urban complexity of the selected case study, US Metropolitan Counties, where the evolution follows historically market forces (Salat, 2014) and daily movements. Additionally, the quest for validated and consistent measurements of the infection spread at the county level is still an evolving work in progress, underlying once again that the work itself may last and observe data for years, before providing "definitive" results.

Possible problems related to the scale issue refer firstly to the lack of a causal research of any relationships between the variables analysed; secondly, to the arbitrariness of County units, as any other boundaries, which highlight several associations which may change using different scale levels and administrative definitions (Cordes and Castro, 2020). Nonetheless, the county level basically is an administrative or political subdivision of a state that consists of a geographical region used for administrative or other purposes and can cover some levels of governmental authority. Third, it has been frequently reported that several wealthy people left the main US cities during the several COVID-19 waves, to move in their second homes

(Quealy, 2020), often located in the countryside. However, when processing data, this process has not been considered since it is not yet available.

Finally, considering the focus on a revolutionary crisis phenomena broken out at the beginning of 2020 (and still going on), the thesis suffers a limited access to high quality and quantity of literature, although journals are progressively publishing in parallel with the overabundance of articles published almost daily online, in newspapers, medical journals, bulletins, magazines, periodicals and so on. Among different data-sources, the challenge is to find useful data for this research and needs and then to be critical along the selection. Furthermore, this condition drives also the definition of the specific case study, that due to data-availability finally corresponds with US Metropolitan Counties. Deeper researches in the European urban contexts (mainly explored between 2020 and 2021) underlined a lack of good data collection, a difficulty in developing comparable data, as well as the absence of a consistent and reliable mathematic-base, from which starting the quantitative analysis and model regressions. In order to set up a statistical analysis indeed, there are some quali-quantitative prerequisites that need to be satisfied by the statistical sample, and that from the US-fonts demonstrated to be more able to fulfil these requests already at the beginning of this work. First of all, US data at the county level were already responding to some quality criteria in terms of updating, coverage and accuracy of the information contained (GSBPM, 2013). Moreover, despite the number of observations in the sample is not the most important factor and sometimes it can increase the risk of bias, having thousands of observations referring to the same geographical/administrative level seemed a good starting point. These requisites were suited for both dependent and independent variables, as the first ones (COVID-19 variables) were constantly and uniformly collected and updated, while the second ones (spatial and socio-economic variables) were uniformly collected, numerically relevant in terms of available categories, quite recent (most of them are yearly updated) and easily accessible from public data-bases. On the contrary, the European case study (both in general and in also in case of specific countries) did not present an adequate data-set, as the full coverage of data was firstly made available at "NUTS" level [6](Nomenclature des unités

[6] As understandable from the official EC-Eurostat site, since 2003 the European Union adopted the Nomenclature of Territorial Units for Statistics or NUTS (French: Nomenclature des unités territoriales statistiques), that refers to a geocode standard for referencing the subdivisions of countries for statistical purposes. The current "NUTS 2021 classification" is valid from 1 January 2021 and contains 92 regions at NUTS 1, 242 regions at NUTS 2 and 1166 regions at NUTS 3 level. However, not every countries present every

territoriales statistiques) that contains firstly a statistical perspective and not always an administrative, geographical and socio-economic one. Moreover, while the US county level guarantees a spatial scale of analysis that is quite deep and definitely closer to the local dimension, on the contrary the European NUTS-definition is limited to the "provincial"/ "departmental" or "contea" level, typical of states such as Italy, France, Sweden, Germany, Spain, etc. This spatial limitation, as stated also by Amdaoud et al. (2021), highlights then high heterogeneity at both regional and local level that is often related to the governments and subnational decisions, more than to the NUTS socio-economic and spatial data themselves. This means then that in the current research context, the adoption of an European case study would have implied an understanding of elements which are not so close to the "author field" (like policy factors at different levels, government dynamics, health-departments functioning, etc.) with the risk of losing the spatial-planning focus of the thesis while confounding possible "endogenous" factors in the final interpretation of the work.

However, in case new European (or even better, Italian) urban data will become available in the coming months and their spatial level would allow for coherent and more local comparisons, new work may then hopefully replicate the model applied to the US and analyse also a similar European context (or subnational one).

All this to say that there are unquestionably further improvements that should be considered but, due to the condensed time and pandemic crisis characterising this doctoral program, they can represent a modest result worth attention.

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level of division, as it depends from their size. In a nutshell, the NUTS hierarchical system contains three levels of analysis of the EU regions: NUTS 1: major socio-economic regions; NUTS 2: basic regions for the application of regional policies; and NUTS 3: small regions for specific diagnoses (EC-Eurostat official page: https://ec.europa.eu/eurostat/web/nuts/background, last access: August 2022).

1.5 Contribution of the research

Because of the ambition to address the two fundamental population factors of density and population size and their role in the spread of COVID-19, the research has the potential to make several theoretical and empirical contributions to the existing knowledge on this topic. As a matter of fact, this research arises from the increasing belief that when understanding the response of urban environments in times of crisis, an important contribution is offered to urban science and planning.

Today, scientists, planners and geographers largely agree that urban characteristics directly affect life and ecosystem quality through several spatial configurations, ongoing processes in time and space, and planning policies. They also recognize that the most of stable urban elements can lock cities into either desirable or undesirable trajectories. Furthermore, the notions of resilience, adaptation, transformations (and so on) are not anymore confined to academic discourses: they are becoming increasingly prevalent in urban policy and planning documents around the world (Lu and Stead, 2013), and are progressively involving professional and expert way of working and dealing with changing urbanised contexts. Definitions and interpretations of these concepts are developing and gaining attention in spatial planning and policy-making to cope with disturbances, unpredictable events and climate uncertainties. Thus, it is likely that the unexpected changes in the use of urban space provoked by COVID-19 may urgently require resilient, adaptable and implementable solutions to be applied, among the other fields, also to urban environments.

That clarified, it might be assumed that under the current pandemic crisis, the current knowledge on diffusion theory applied to the virus spread can find several similarities with the urban-system understanding. And in this context, the notion of resilience can find a fertile ground to address several challenges for two reasons: it provides a new paradigm for framing uncertainty and vulnerability in spatial planning and urban development, while indicating responses, adaptation and preparedness solutions; and it offers an alternative model for developing strategies and approaches to deal with large-scale changes impacting at several levels and along different times. Consequently, there is the reason for **integrating resilience thinking in the conclusive part of the work,** when the combination between theoretical background and analysis results will be developed (Sharifi, 2019), and for proposing measures that maintain our urban spaces liveable and healthy. The physical settings represent indeed one of the main channels through which planners make interventions in the urban system and in its functioning, but there is evidence to raise questions about how urban-life will be in the post-Coronavirus crisis.

Therefore, for the existing scholarship on the theoretical topic of "density and population size dealing with COVID-19 pandemic", the findings should make an **innovative contribution** to the way in which these properties (observed with others) are considered in understanding the built-environment we live in, reducing long-term risks, enhancing urban resilience and identifying the key characteristics that are essential to contain similar risks and patterns in the future (León and March, 2016; Elmqvist et al., 2019). Furthermore, the results might progressively induce scholars, planners, local and international NGOs, and civil societies to enable built environment to function through more flexible properties than in the past and at present (Jabareen, 2006). Undoubtedly, this exercise of understanding represents an **opportunity to evolve the complexity of the city into something new**, to support future urban development processes, to design with **creativity** and to practically turn potential threats into a benefit for the urban system, thanks also to **new key-metrics and needs** that will emerge from the literature and practices. These opportunities assume even more weight in times of pandemic crisis, as they underline that it is not too early to wonder about the role of our studies and professions may have in adapting and changing the new city-needs.

Thus, it can be stated that this research has the potential to:

(1) contribute to the existing knowledge on pandemic-crisis and diffusion theory in urbanized contexts, with new reflections and observations;

(2) highlight new urban needs (as well as aspects that will not change) in place facing rapid and unexpected disturbances like the COVID-19 crisis and try interpreting them through the resilience lens;

(3) define some possible suggestions for planning field, with a specific focus on the urban issues here addressed, able to combine the theoretical level (starting from literature review and further comments) and this practical study based on the COVID-19 pandemic-experience at the US metropolitan county level.

Moreover, in terms of academic contents, the current work can offer (a) a new product where the urban environment is read as complex adaptive system (starting from some ecological principles and then developing further); (b) a contribution to the long-term understanding of cities affected by great changes (to be added to others, like climate change and energy transition, already ongoing); (c) a new topic to consider in the planning field, as if this global experience brings us the opportunity to reflect on the ways we developed and managed our cites till today (Roses et al., 2020).

1.6 Target subjects

Since this study has the twofold potentiality to contribute to the emerging theoretical debate on "density and population size responsibilities about COVID-19 spread" and to produce insights for its practical understanding in response to the COVID-19 crisis, it is important to direct the work to **both academics and professionals** working in the built-environment and city-planning sectors.

Once clarified the main domains of interest, a possible target subjects might correspond with:

- Academies with experience in the field of socio-ecological resilience and its co-evolutionary interpretation to address crisis;
- Academies and experts with experience in the sector of urban morphology and urban challenges in face of disturbances, even better if these disturbances comprehend disease issues;
- Academies and new research groups who feel particularly concerned with the topic of the COVID-19 crisis and the related transversal impacts on different disciplines like urban planning and policies;
- Central figures in prominent architectural firms and organizations who are already working in the field of planning in time of and post COVID-19;
- Practitioners directly involved in urban and architectural practices, and actively involved in meeting new research findings on urban science, in the light of the changing conditions that this crisis will impose mainly at metropolitan and city-level.

That said, the outcomes of the analysis both in the form of theoretical background and of practical findings, might enable researchers and professionals to work and elaborate the body of new insights and reflections.

CHAPTER 2
THE THEORETICAL BACKGROUND

There is a density level in NYC that is destructive.
It has to stop and it has to stop now.

NYC must develop an immediate plan to reduce density.

Tweet by NYC Governor Andrew Cuomo, 22 March 2020

2.1 Introduction

In this chapter of the thesis, the topic of the work is presented and deepened, through the use of theories, concepts and literature contributions. Among the majority of recent research on built-environment factors leading to greater coronavirus diffusion, density and population size have been addressed as dominant factors. Health, social, cultural and economic aspects are also important and often addressed in several studies, together with temporary socio-cultural conditions (as mass gathering events or destination, where the mass of people increased the virus circulation). However, in this part of the work the attention turns firstly to the theories behind the fields involved, and then moves to the two most discussed features and on the literature debate around them.

Thus, once introduced the idea of urbanities seen as complex and dynamic systems, then the chapter explores the geographical understanding of the crisis-diffusion phenomena and then, lastly, the role in these two specific aspects during the COVID-19 pandemic crisis. The system thinking approach and urban resilience will be deepened, in order to build also the basis for further reflections that may follow in the discussion and conclusive parts. It has to be said that the overmentioned concepts can represent, according to the readings and knowledge developed, just a possible direction to move toward. Moreover, a specific zoom on the issue of pandemic, meant as a source of crisis pressing on complex systems, is provided to guide the understanding of this phenomenon to a more critical interpretation and contribution.

2.2 Complexity and system theory as a background for the thesis-focus

According to Springer, "Systems theory focuses on **structures, relationships, and interdependence between elements**, while complexity theory refers to the **heterogeneity** in the various subsystems of an organization and how parts at a sublevel in a complex system affects the emergent behaviour and outcome of the system" (Amagoh, 2016). In this context, considering the complex phenomena analysed and the field of urban planning to which the thesis belong is a useful way to deepen these topics and integrate their characteristics in the objective of the thesis.

Now more than ever, it is clear that the multitude and the rate at which change is currently happening is exceptional by magnitude and rapidity, and often unpredictable. The diffusion of this new virus is highlighting with no doubt that the network in which COVID-19 spreads easily is highly complicated, interconnected and not only made of "material" components but also (and mostly) of "immaterial" ones. In this sense, evidences from this (among other) crisis increasingly suggest that social and ecological systems are truly interconnected across spatial and temporal scales and for this reason are also referred to as social-ecological systems (Berkes and Folke, 1998). In this scenario, given the global goals of sustainability, cities today have to face with a difficult task, as they are experiencing unprecedent rates of rapid urbanisation, stressed and aging infrastructures, social inequalities, economic crisis, infectious diseases and the increasing impacts and concerns of climate change, natural disasters and other diffusion events (concerning different events/elements). Thus, it turns particularly useful to consider urbanized contexts as complex systems, more and more vulnerable to several crises and changes. These aspects motivate firstly, the need to consider several aspects when trying to understand a specific phenomenon happening in an urban context; secondly, the need to integrate more and more of the options available: adapting, transforming, expiring (as never happened before), and so on. In the following paragraphs, the theories of system thinking and the concept of resilience (according to a specific interpretation) will be deeply framed in order to create a continuum with the diffusion theory presented afterward and to represent a theoretical basis for the further analysis of the two specific features of population density and size in dealing with the COVID-19 crisis.

2.3 System thinking and System ecology

Despite the increasing signals of the evolving and dynamic global circumstances we live in, together with increasing dynamic phenomena in several fields (see section 3), the traditional paradigm that dominated up to the first half of the 20th Century has to do with the Newtonian physical perspective. The idea of an ordered, continuous and linear universe was the rule to study big systems by analysing them in terms of the smallest parts (Capra and Luisi, 2014). This paradigm covered also other domains, as social and economic sciences, as well as urban planning, design and architecture, supporting the principles of order, efficiency and simplification. However, from the second half of the 20th century, the trust in predictability and "optimal state" of wellbeing began to contrast with new scientific development, deeper experience-observation and the emerging holistic perspective. The new approach, then named "system thinking" or "system theory", has its roots in the field of biology developed in Europe during the 1920s. The revolution introduced by its exponents focuses on the crucial passage from the rational-perspective, insufficient to shed light on the complexity of the real world, to the drastic awareness of world chaos, disorder and non-linearity (Capra and Luisi, 2014).

The new approach gave birth to a totally new way to look at things, where **relationships, connectedness, patterns and contexts are central**. For these reasons, the new perspective assumed the name of "system thinking/theory" (Von Bertalanffy, 1950), and opened the pathways to the complexity theory. This new approach, according to the father of contemporary systems-ecology Crawford Stanley Holling, was found to share several things with the ecological science.

Indeed, because of the presence in ecology-studies of exchanges between biotic populations and physical environment, there was reason to focus on the increasing impact of human activity on the biosphere, including environmental changes and ecosystem degradation. Furthermore, due to the abundance of fields involved in ecology in relational terms, the ecologist dimension became particularly close to the concept of system thinking. And in this sense, it became also evident that the system ecologist proposed was demanding a **new perspective**, where ecosystems are seen in **constant fluctuation** and **in orbit around**

multiple and temporal stable states. **Future is uncertain** and the main drivers of ecosystem correspond with disturbances and shocks.

This modern view on system ecology was officially published in a seminal article in 1973 titled "Resilience and Stability of Ecological Systems", in which Holling underlined the weaknesses of the traditional stable and equilibrium-centred view as "it does not always provide a realistic understanding of the systems' behaviour" (Holling, 1973). This new perspective, considered a "complex-systems view" to ecology, introduced the interesting concept of resilience at ecological level and opened new debates on its interpretation. Further details on this topic will be deepened in the next paragraph.

2.3.1 The concept of Resilience

Under the overmentioned circumstances, the **concept of Resilience represents a possible perspective to address the above challenges**, as it has to do with the unpredictable nature of the future, while offering a different perspective (in comparison with traditional ones) to understand and deal with change. However, because of the on-going and often confusing debate on sustainability and resilience, an effort on how the world is viewed in relation to our actions, is urgently required not only for the years to come but also in the long-term future.

According to many scholars belonging to the spatial and planning fields, resilience is a contested concept which is "in danger of becoming" a vacuous buzzword as a result of its "overuse and ambiguity" (Rose, 2007). It appears that resilience is replacing sustainability in everyday discourses, they even overlap sometimes, and over the past decade, an increased use of the term in planning, policies and practice has faced climate change uncertainties and socio-economic insecurities (Davoudi et al., 2012). Because of the increasing uncertainties of climate change, extreme weather, pandemic outbreaks, civil unrests, terrorist attacks and economic instability, resilience has been presented a useful approach to support the management of these unpredictable times. Folke highlights that resilience thinking has become part of practice, policy and business across the world, extending from poverty alleviation to political frameworks and business strategies in response to change and crisis, not only to survive, but also to evolve (2016). Meerow et al. state that the increased popularity of the term, in both academic and political discourses, has seen a dramatic rise of resilience insights in many fields (2016). Building resilience has also become a central concern of international institutions and agreements as the Intergovernmental Panel on Climate Change (IPCC), the United Nations (UN), the 2015 Paris Climate Change Agreement (COP 21), the 2021 Glasgow Climate Pact (COP 26) and the UN-Habitat III on Housing and Sustainable Urban Development, who adopted it as a key approach for climate change mitigation and adaptation strategies, as well as for environmental management, socio-economic development and spatial planning. Despite this wide use, there is no clear consensus on what resilience means and who it can be really useful in practical crisis-scenarios, except from the assumption that "resilience is good".

Among scholars, the concept of resilience has been discussed for over forty years within different disciplines as ecology, geography, biology, social psychology, urban studies, regional economics, and so forth (Alexander, 2013). Thanks to these **multi-disciplinary contributions**, researchers have seen an evolution of the meaning of resilience and recently, a shared approach to **resilience related to territorial systems has emerged as a significant concept and policy response** in an era of global concern about disasters and risks (Brunetta and Caldarice, 2019). Several publications on resilience are actually contributing to face the gradual and often uncontrolled "planetary urbanization" (Brenner and Schmid, 2011), wondering if resilience is a mere catchword used by policymakers and organizations to categorize their actions, or instead it contains positive drivers of **innovation, adaptation, creativity and evolution** of dynamic and living contexts.

Going back to the roots of the concept, the etymology of resilience stems from the Latin word *resilio,* meaning "to bounce back" (Davoudi, 2013). Thus, it is not surprising that the concept is often used as the capacity to rebound, to resist and to maintain a certain equilibrium. This approach, called "engineering resilience", refers to the system's capacity to keep optimal stable state to address change, or to quickly bounce back to its previous condition after the perturbation (Avallone et al., 2006).

Barely used until the middle of 20th Century, in the 1960s, the ecologists began to apply and develop the concept mainly thanks to C.S. Holling's seminal article "Resilience and Stability of Ecological Systems". Through this first effort, he introduced resilience as a way to understand nonlinear dynamics in natural systems and to recognize the capacity of ecosystems to absorb change, or more specifically, how to persist developing in the original state subject to disturbances and changing conditions (Holling, 1973). He mainly investigated how ecosystems relate to random events and instability of temporal and spatial scales and defined resilience as **persistence** of relationships within a system, as a measure of the ability of systems to **absorb changes** of state variables, driving variables, and parameters, and **still persist** (Holling, 1973). This second view, called "ecological resilience, concentrates on both the ability of systems to maintain basic functions while persisting in face of shocks, and on the change-amount that the system can absorb before reaching a threshold and then shifting to a new configuration. Because of this resilient perspective, the system is never static but can fluctuate impressively (Holling, 1973).

With time and several studies, the primary definition of "engineering and static equilibrium" and the bit-more active one, evolved toward a "dynamic" view, called "evolutionary resilience". Thanks to the development of the theoretical basis for resilience dynamics emerging from the comparison of the ecosystem studies (Folke, 2016), this new perspective describes the capacity of systems to continuously reconfigure and adapt its internal structures in a spontaneous way, minimising the impact of shocks (Davoudi et al., 2012), and constantly evolving towards new trajectories of growth. Indeed, in contrast with the idea to "return to a normality" (either old or new), the evolutionary interpretation of resilience proposes a continuous and restless process of adaptation. The existence of a single equilibrium is rejected, and a **multiple equilibria asset** is proposed instead. In this case, instabilities can reverse from a system into another, bouncing forth instead of bouncing back.

Going beyond the notion of stable equilibrium, either mono- either multiple-, after some years literature developed the awareness that "*people and nature are interdependent systems*" (Folke et al., 2010) and thus, resilience cannot conceive "a return to normality" but rather the **capacity** of a complex socio-ecological system **to change, adapt or transform** in face of stresses and strains (Carpenter et al., 2005). According to the geographical point of view, adopting a resilience approach has not to do directly with risk and vulnerability but actually to something more proactive and prospective, where the ambition is to learn how to coexist with risk and how to take seriously the ability of people and places to foresee, bear, adapt to, and finally minimize the harm from unescapable threats like pandemics, economic crisis, terroristic attacks, climate change and political turmoil (DeVerteuil, 2018). This capacity of a system to overcome external shocks while moving to a new equilibrium stage based on system's persistency and robustness finds a solid background in the Adaptive Cycle of system development, introduced by Holling in 1996. Through this metaphor, Gunderson and Holling then articulated the pillars of the socio-ecological resilience approach by representing the main concepts in the **panarchy model** (2002). Socio-ecological systems (SES) refer to a "coupled dynamic relationship in which humans, their social structures and their biophysical environment interact with each other as parts of one interdependent system" (Du Plessis, 2008).

In the context of the adaptive renewal cycle (Figure 2), ecosystem behaviour can be described as the dynamic interaction among four basic functions: exploitation, conservation, release, and reorganization (Holling 1986).

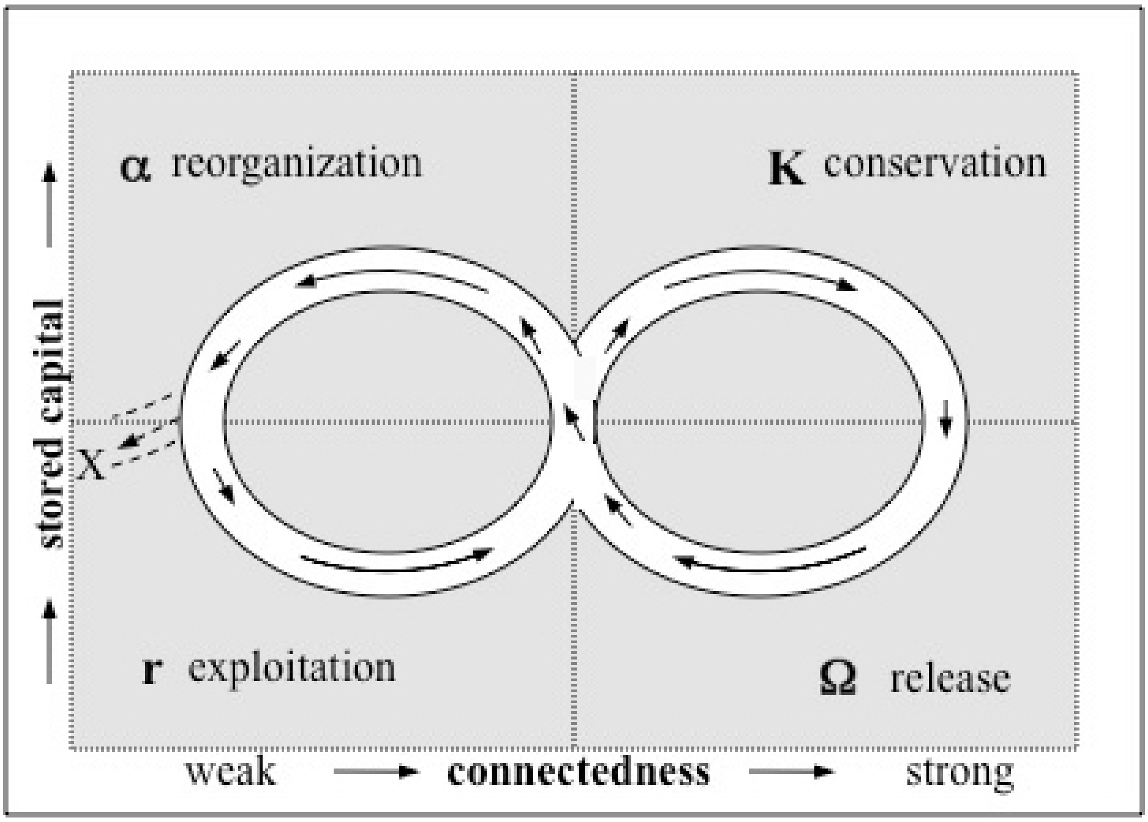

Figure 2 - The adaptive renewal cycle (Gunderson and Holling, 2002).

The first two are similar to ecological succession, as:

- **Exploitation** is represented by those ecosystem processes that are responsible for rapid growth of disturbed ecosystems characterized by the occurrence of r-strategists that can easily capture accessible resources. Therefore, while the exploitation grows, the system begins to lose part of its flexibility. This stage is therefore called the r-stage in the model.
- **Conservation** occurs when slow reserve accumulation takes place that builds and stores increasingly complex structures. This stage is referred to as the K-stage.

The next two consist of:

- **Release** phase, also-called omega-phase (Ω). It takes place when the conservation phase has built elaborate and tightly bound structures that have become "overconnected", so that a rapid change is generated. The system then becomes fragile.
- When the stored biomass is suddenly released, the unexpected destruction creates both internal destruction and external disturbances. This process of change both destroys and open to the opportunity for the fourth stage, **reorganization**. In this phase, called the alpha-phase (α), released materials are mobilized to become available for the next exploitation phase.

This architecture of "apparent simplicity" is strictly correlated with the collapse of the system: even a small disturbance falls into a collapse, which then moves into the reorganization phase. Over time, these cycles become part of a spiral trajectory, with crises as occasional catalysts of change as well as opportunities to develop means and capacities to adapt (Walker et al., 2020).

Hence, while the stability and productivity of the system is determined by the slow exploitation and conservation sequence; resilience is determined by the effectiveness of the last two functions, often referred to as the back-loop phase. This implies that as systems mature, their resilience reduces and they become "an accident waiting to happen", and when systems collapse, "a window of opportunity" opens up for alternative system configurations (Davoudi, 2012). Therefore, the omega phase introduces by Gunderson and Holling represents the time of greatest uncertainty yet high resilience; a **time for innovation and transformation**, a time when a **crisis can be turned into an opportunity**. As the world is "a becoming", resilience perspective can be thought as the ability of complex systems to persist in the face of uncertainty, disruption, and change, proposing a "continually changing process" (Davoudi et al., 2012). As such, evolutionary resilience can support the understanding of complex systems that not only undergo unexpected and disastrous changes driven by external shocks and events, but also experience gradual adaptation along their existence, which is associated to processes of self-organization. In this context of research, these reflections can also guide the understanding of the pandemic pressure and the role of the urban elements in dealing, reacting and answering to it.

Early on, Holling and Goldberg (1971) pointed out the **remarkable similarities between ecological and urban systems**, focusing on their functioning as interdependent systems, on their degrees of self-organizations, on their complexity and unpredictable feedback processes which operate at multiple scales and timeframes (Davoudi et al., 2012). Additionally, they viewed a city not as a homogeneous structure but rather as a "spatial mosaic of social, economic, and ecological variables that are connected by a variety of physical and social dispersal processes" (1971). Thus, being cities considered a typical sample of complex adaptive transformations (Batty, 2013), the evolutionary definition of resilience is considered the most proper to understand urban contexts. Urban resilience then can be considered as the capacity of active and interactive social, economic, environmental and physical levels to persist and even succeed in response to external stressors and internal transformations without reaching a breaking point or a permanent lock-in condition (Feliciotti, 2018). Within this scenario, Meerow et al. defined urban resilience in a dynamic way affirming that: "*Urban resilience refers to the ability of an urban system - and all its constituent socio-ecological and socio-technical networks across temporal and spatial scales - to maintain or rapidly return to desired functions in the face of a disturbance, to adapt to change, and to quickly transform systems that limit current or future adaptive capacity*" (2016, 39). The idea of (co-) evolutionary resilience becomes then a way to understand cities-behaviour in a state of non-equilibrium. **This perspective can guide the final steps of the thesis, especially when observing the COVID-19 crisis and related urban impacts, with the goal of integrating the planning indications.** Another simple definition of resilience is the ability of a city to absorb disturbance while maintaining its functions and structures (Holling, 1987, 2001; White, 2010).

In this last description, it is evident that socio-ecological resilience has direct influences also on **spatial level**. As spatial systems have been identified as the perfect sample of complex systems, resilience concept can firmly enter in the planning theories and practical debates. According to Portugali, the city can be understood as the product of self-organization (2012). In this perspective, resilience at urban and spatial level is strictly connected to **change** on the current path of development adapting, improving, and innovating. It also implies that territorial systems continually self-organize and adapt in the face on ongoing and unpredicted changes (Brunetta and Caldarice, 2019). Thus, resilience provides a means not only for recovering from shock and gradual changes but also to adapt to and somehow "anticipate" possible future stressors occurring at physical level. Within this new statement, it is then fundamental to study dynamics of change over time and to frame it in complex systems (see the further two sections).

However, this vision might seem somehow in contradiction with the idea that cities are the symbol of planned action with rigid boundaries, districts and urban fabric. Spontaneous self-organization looks diametrically opposed to planning which is aiming to controlled order (Forgaci and Van Timmeren, 2014). Thus, when applying resilience framework to the built-environment features, there are lot of connections with **complexity** as well as with the physical capacity to face disturbances. In this sense then, some clarifications have to be done in relation to complexity theory.

2.3.2 Complexity and cities as complex systems

Up to here, the system thinking and the evolutionary resilience perspectives suggest that the world and cities we live in are complex and ever-changing systems that are far from equilibrium, stability and permanence. Thus, understanding complexity is a fundamental passage to recognize system properties and how they work together in adapting to and dealing with any kind of change.

Complexity theory is a relatively recent science which has emerged from system and chaos theories, then becoming an independent field of study (Phelan, 2001; Abraham, 2011). With its origin in the general systems theory, cybernetics and system dynamics of the 1920's, since the beginning the concept included the ideas of self-organization, occurrence, non-linearity and adaptability. Despite similarities with system theory, complexity has a different approach: while the first one refers to a "static structure, ordered hierarchical system of parts and elements that existed in equilibrium and could thus be optimised in terms of their functioning design" (Batty and Marshall, 2012); the second one claims that **systems are far from equilibrium** and, because of their dynamism, can move into a new type of state (Gunderson and Holling, 2001).

Moving back to its origins, "complexity" comes from the Latin "*complexus*" which means "Consisting of many different and connected parts" (Oxford Dictionaries, 2015?). In 2007, Gershenson provides another interpretation of the term, stating that "in order to have complexity, there is a need of two or more distinct parts, that are joined in a way that it is difficult to separate them". This creates a **dual condition** where the two parts are simultaneously distinct and connected.

For this reason, complexity theory was developed as a useful tool to read the complexity of the world. And it does this, not only through the study of the individual parts involved but also of the connections between them. Thus, complexity theory studies complex systems, focusing on the relationships between agents and the dynamic nature of systems. The emphasis here is on the rules that agents follow and how these basic rules can produce complex and evolving behaviours in a system (Stroh, 2005). In addition, complexity theory aims to understand the interactions of these elements and how these interactions change over time within the system's environment (Cilliers, 1998). This basis frames bottom-up phenomena of self-organisation and occurrence at several levels: the attention here turns to urbanised environment as argued below.

When Holling and Goldberg (1971) tried to understand cities, they opted for a comparison between urban and ecological systems. Despite the differences among the two are evident and had to remain distinguished, the idea was to suggest the use of ecological approach to read and solve problems that occur in all complex systems (Holling and Goldberg, 1971).

Therefore, it makes sense to demonstrate that the application of models and methods typical of ecology or other artificial systems, as the urban ones, could work on the basis of the general characteristics that all complex systems have in common. More in depth, they make evident that both urban and ecological systems share four key features to all systems:

1. **System interaction**: it has to do with the impossibility to understand the whole system while studying their parts separately. In fact, both ecologic and urban systems present evolving properties that do not represent the individuality of any of their singular components, but rather the outcomes of the interaction between them. This is evident when any small interventions in an ecological or urban system produces unpredictable "echo" in several directions (Holling and Goldberg, 1971).

2. **Historical succession**: this common property is related to the "path dependency" that both systems possess, in the sense that future development paths are necessarily built on present conditions that, in turn, depend on past ones. Thus, a sort of "historical quality" becomes part of both ecological and urban contexts and enables the understanding of present and past events.

3. **Spatial interlocking**: this character comprises the spatial dimension of both ecosystems and urban systems that, being a mosaic of heterogeneous parts, are affected by events also according on where these occur. Thus, any change at one spatial point will certainly influence other points in space where a certain dependency in terms of location, density, accessibility, and so on, exists.

4. **Non-linear structure**: this property relates to the fact that in complex systems, outputs and inputs are not proportional, as shown also in the panarchy model of adaptive cycle presented earlier. Hence, as stated by Alberti (2007), also a very small change can provoke great qualitative differences in the consequent impacts. Following this, minor stressors in some parameters may be repetitively amplified through scales and make echo in the system.

This exploration led the two authors to affirm that urbanized contexts, exactly like natural ecosystems, can be theorized as complex adaptive systems, confirming then the similarities between ecological and urban sciences. Despite the empirical perspective, the model of

Panarchy model of adaptive systems becomes then the symbol of a new generation of management and design practices based on the temporal state of a system as it can move from one phase to the next, and on the cross-scale relations in both short and long-term perspective. Therefore, when trying to understand urban dynamics, logics of simplification or maximisation may have undesirable consequences. In recent years, the idea that cities can be read as self-organising systems of remarkable complexity has grown also in the scientific literature and debate, thanks to several publications (Portugali, 2011, Batty, 2013b, Salat et al., 2014). To Portugali (2011), complexity theories can represent a solid mathematical and theoretical basis to understand and observe many urban phenomena. In short, they provide a "single theoretical basis to a variety of urban phenomena and properties that so far were seen as independent of each other and thus interpreted by reference to different theoretical bases" (Portugali, 2011, p.96). Complexity theories offer a new vision to understand cities under the fundamental properties of complex systems. This point leads to the basic awareness that cities are complex adaptive systems (CAS) and as such, it is not possible to study any of their part in isolation, being so strongly related to other elements of the city structure (Reif, 1973).

Hence, as cities are seen as complex adaptive systems, the concept of resilience can become increasingly useful and suitable to address change, uncertainty and variability in urban systems. In this context, this interpretation of urban system may result particularly adequate when addressing the diffusion issue, which certainly contains several similarities with the system and complexity frameworks here described. Indeed, so far it becomes evident that the urbanized contexts we live in are far from equilibrium, stability and permanence: on the contrary, they follow a more dynamic and fluid behaviour where things constantly change.

For these reasons, when trying to build a theoretical framework behind the crisis-experience provoked by COVID-19, the study of the diffusion theory proposed by the pioneering studies of Hägerstrand and Haggett seems to fit particularly well into this background, **as several concepts are actually shared** by the different disciplines. One among the others, the idea of change, process and dynamic which are behaving and moving through space and time. Before passing then to the focus on two specific urban features, here referred as population size and density, and to the understanding of their role in dealing with COVID-19, it is useful have clear the diffusion-behaviour and processes in spatial and timing terms.

2.4 Notions of Diffusion Theory as a framework to address the thesis-focus

The global COVID-19 emergency has turned public attention to the **vulnerability** of large urbanized contexts facing a pandemic, while scholars discuss on the major contributors. But by stepping back from the urban exposure and main responsibilities to the contextual, geographical and health aspects of the COVID-19 outbreak, it is possible to firstly offer a framework of notions related to the crisis phenomenon here addressed. More in particular, when having to do with infectious diseases, it is possible to find knowledge deepening the concept of "Diffusion". A term that is meant, in longstanding geographical terms, as a dynamic movement of an element/an event in space and time (Hägerstrand, 1967) and, read in this way, with several aspects in common with the previous urban theories described. Clearly, in this scenario, infectious diseases are a form of spatial diffusion which is interesting to address having clear both the **general concepts behind its behaviour** and then the **main channels favouring its spread** from place to place and through time.

Thus, in this section, more attention will be offered to the pandemic diffusion dynamics so as to frame and start discovering the insights and implications of COVID-19 spreading in urban settings characterised by high levels of complexity and changing-processes, and where successively the features of population density and size will be deepened.

When observing the diffusion of a disease, the context-conditions for its spread are mainly related to the possibilities offered to the virus to "escape" from an area in which it broke out and then "move" to another one. This obviously means that several elements can influence this transfer, especially when the starting context offers socio-cultural, environmental, economic and commercial conditions where people concentrate, move and encounter. These elements, as already studied for China, Japan, US and Northern Italy (Davahli et al., 2020; ISS, 2020; Murgante et al., 2020; WHO, 2020) may have influence both the dynamics of the virus penetration and also the risk-intensity referred to as multiple "epidemic hot-spots".

In geographical terms, the outbreak of a virus represents a terrible and alarming case of spatial diffusion, which is a very popular topic studied in this discipline. When speaking about "diffusion" in geography, the **original idea introduced by Hägerstrand** (1967), indicates the movement of an event (or a cluster of events) through space and time. This concept, very logic but never explained in theory before Hägerstrand pioneering work, introduces the idea of a process and the representation of a pattern, meant as the "product" of the event-movements in space and time (Morrill, 1970). For these reasons, diffusion is a crucial matter of study in geography as it can be referred to many different cases and situations, from migration phenomena to financial crisis, from human and physical geography to plagues diseases, and so on. Not only, starting from this vision, it is possible to introduce several points of similarity with the urban complexity and systemic perspective, since in both scenarios the observation of a phenomenon is never stable, follows an unplannable process, and moves through time and space.

The observation of these facts played by the geographers in different situations, has pointed out some basic elements that tend to repeat themselves, and that may be interesting also in this analysis of COVID-19 spatial diffusion. A first classification when observing spatial diffusion see a distinction between **expansion and relocation phenomena**.

While the first one means that the spatial-temporal extension of a given event (or state) tends to cover and fill the available space; the second one refers to the physical move (and abandonment) of the original-event site towards a new one. Haggett proposed a representation of both categories in 2001:

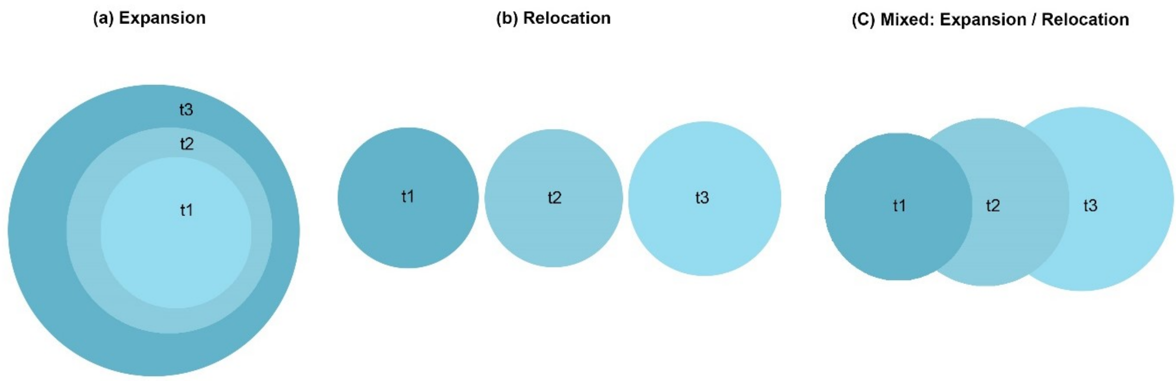

Figure 3 – Types of Spatial Diffusion Processes. Expansion, Relocation, Mixed (Source: Personal elaboration from Haggett, 2001).

In case of the expansion (infectious disease can be considered as a "prime sample" of contagious expansions, according to the Geographer Matt Rosenberg[7]) several rules can be identified (Haggett, 2001) and distinguished according to their behaviour:

[7] More information about M. Rosenberg, an award-winning professional geographer, and his interpretation of Diffusion-theory applied to COVID-19 behaviour, can be found in the article "Common Geography Terms:

1. **Contagion**: it refers to a typical local expansion, where there is a contact between the space/event bringing an "innovation" and those not influenced yet;
2. **Network**: it has to do with a networked structure where the contact between subjects happens because of the presence of social networks, both local and global, as well as of major transport infrastructures and networks;
3. **Hierarchical**: it follows an expansion process where the diffusion is expanded through advantaged communication channels and, firstly, between the most important centers. In this case, also the main transport and communication paths can favour the diffusion of the "innovation" in both spatial and timing terms;
4. **Waterfall**: it follows a typical structure that generally starts very fast with a top-down method (e.g. from major centers to minor ones), and then slows down when it goes back with a bottom-up approach (e.g. from minor to major units).

From this distinction, it can be stated that first theories and observations of COVID-19 behaviour, recognize a combination of the above-mentioned diffusion rules (Murgante et al., 2020; Davahli et al., 2022). Moreover, starting from the epidemics analysis suggested by Haggett and Cliff (2006), it is possible to see these diffusion processes as different spatial diffusion waves, with either a single or multiple locations from which spreading by different processing, while reaching wider areas. The two geographers, together with Smallman-Raynor (2008), pointed out the similarities between the diffusion of epidemics in space and time and the "wave-nature" of epidemics themselves. Furthermore, they realized that in this case, the diffusion process is actually a combination of expansion and relocation phenomena: in fact, an epidemic phenomenon usually begins in a certain area, then rises in space, and sometimes it relocates somewhere else from the original place, to grow in a newly impacted region. Thus, it can be stated that the diffusion process of an epidemic is "contagious" when the infection spreads by direct contacts, "network" if it is developed following relations between persons and places, "hierarchical" if major centers influence a high set of lower centers, and finally "waterfall" when the diffusion is generally guided by a top-down approach starting from stronger centers. Not only and interestingly, this behaviour highlights several connections with the basic complexity features presented above (see Section 2.3), as it has to do with: the (i) **system interaction**, where interaction is set against individuality,

Diffusion How Things Spread From Place to Place", published on "ThoughtCo." on July 11, 2019: https://www.thoughtco.com/diffusion-definition-geography-1434703 (last access: August 28, 2022).

producing a sort of "echo" in several directions (Holling and Goldberg, 1971); the (ii) **historical succession**, where future development paths are necessarily built on present conditions that, in turn, depend on past ones; the (iii) **spatial interlocking**, where a mosaic of heterogeneous parts are usually involved; and the (iv) **non-linear structure**, where a very small change can provoke great qualitative differences in the consequent impacts.

That said and back to the idea of "wave" introduced by Haggett and Cliff (2006), in geographical terms five steps can be observed and applied to the virus-behaviour:

A. **Onset-phase**: a new virus, named "innovation", enters a new region where a vulnerable population is open to infection. Usually in this case, only a single place (or a limited group of locations) is involved.
B. **Youth-phase**: in this early phase, the infection rises with rapidity from its original place to more centers. In this phase, previous outbreak experiences and observations, pointed out both local diffusion (by contagion) and long-range spread (by hierarchical and waterfall dynamics).
C. **Maturity-phase**: this phase, where intensity is highest, is attained when the entire region/population is involved in the epidemic.
D. **Decay-phase**: in this descending step, cases are fewer and fewer and a diffusion decline is progressively registered, in contraction than the original diffusion paths.
E. **Extinction-phase**: this conclusive phase of the epidemic reports fewer and dispersed cases, that can usually be met in less accessible areas.

While the available literature and data with this focus are still very limited, and a full validation of these steps would require both international-national analysis of the virus-phenomena and also a conclusive phase of this epidemic which is, on the contrary, still going on, what can be stated so far is that in general this virus is undoubtedly representing a process of change in time and space. In fact, from the first outbreak observations where the diffusion process was mainly characterizing the local levels with high-speed levels of transmission (from the place of origin in Wuhan city and Hubei region), then the infection (also said, in theoretical terms, "innovation") started to take place also at different scales and bit more slowly, from neighbourhoods to entire countries in the five consequent stages. Not only, it is possible to find out that from shorter to medium-longer distances, the diffusion process is related to the transport networks (the public one) through buses, metros, rail and maritime routes, high speed trains and air routes. Moreover, while the so-called "contagion" model can mainly be observed at local level is mostly characterized by rapid transmission, the "hierarchical" pattern has mainly to do with the slower regional and international diffusion. In fact, starting from the first local levels of origin (firstly in Wuhan city and then a neighbourhood in South Korea), then after some weeks the disease arrived in other European and North American countries, favoured by major air connections from Easter to Wester countries (Borruso, 2013).

In conclusion, it can be stated that when addressing the COVID-19 crisis at the spatial level, the field of diffusion theory can bring an interesting contribution to the system and complexity theories where urban resilience is often applied and aimed. In fact, in line with the interest (deepened along this Chapter) on urban systems and spatial dynamics, the observation of a crisis-phenomenon-diffusion highlights even more connections with the **processual-idea of "change" in space and time**. This dynamic event, as better explained along this chapter, has received a lot of attention from decades of urban science literature, which is clearly interested in shifting from a static and unchangeable idea of "urban setting" to a more dynamic, processual and ever-changing "urban system".

2.5 Pandemic crisis as a proxy of urban change

As discussed so far, it is evident that cities are by their nature "complex adaptable organisms", capable of constantly reinvent themselves, sometimes very rapidly that is surprizing and some other times so slowly that it took years to be noticed (Fulton, 2020). Evolutionary resilience is a growing discourse within the wider urban-sustainability umbrella, which assumes that resilient principles constitute a **promising theoretical "toolbox" to understand urban changes**, **improve urban planning, design and quality of life** (Marcus and Colding, 2014; Samuelsson et al., 2019). However, in this context it is necessary to focus on some specific stressors and discount others, as it becomes clear that being resilient to everything is a challenging task (Davoudi et al., 2012). The thesis has then decided to focus on the pandemic crisis of COVID-19 that in early 2020 totally altered our urban lives like a thunderbolt. This upside-down way of living has turned "normal" urban dynamics and shed the lights on the "era of pandemics".

To stress the role of evolutionary resilience in dealing with this specific urban change, the first step turns to the context of study: urban contexts. These ones have fought though any kind of crisis for generations, and during this unexpected pandemic-crisis pick have gained again most of the mediatic and political attentions. Indeed, when reflecting to the history of cities, it even seems that it is impossible to live in a place without changes in that place, according to external events as well as to human uses and purposes. A condition of perpetual disequilibrium dominates at urban level, in parallel with complex dynamics of interaction between human, physical and natural systems (Batty, 2013). However, few people usually think beyond the next few days or weeks. Many persons do not appreciate change in our cities and communities, as change is unpredictable and we rarely know how it will affect our lives (Steuteville, 2020).

But today, the new Coronavirus has spread so rapidly around the world following most of the rules presented in Section 4, that **change has so drastically stepped in our lives and urban habits**. Not only COVID-19 is increasing the risk for people's health, but is also accelerating several other changes that have threatened cities for a long time (Fulton, 2020). In this sense, the idea of "wave" introduced by Haggett and Cliff (2006), where the new event/object moves progressively through space and time producing "cascade-effects", finds several similarities. In fact, because of the progressive virus-spread, urbanized contexts introduced several health-restrictions on the use of public space, quarantine, confinement and social distancing, adding further stress to what is already threating their habits (climate change, energy crisis, pollution, economic instability, etc.). Cities today are facing unprecedent stresses, as the restrictions in the use of public space, the need of new spaces for people (both public and private), and the lack of some resources to make them more independent, efficient and healthy. And more than all, despite geographical differences among different countries, the most striking experience we share today relates to a **deep uncertainty about the future** of our cities and the way we use and make sense of their places, spaces and functions.

Because of these uncertainties, a possible approach that seems to meet the crucial issues of the diffusion-theory and the complexity of urban systems, is resilience perspective which is able to understand if we will incorporate any lessons and then turn them into an occasion to "**bounce forward**" (Davoudi et al., 2012). In spite of the so-called "cliché" to claim that a crisis can be turned into an opportunity for the system, yet never before there is reason to state that cities can really learn a lot from this crisis. By addressing topics as cities, health, urban design, structure and functioning, impacts and consequences of COVID-19 can become an unprecedent opportunity to renovate many characteristics of our urban environments and approach to planning. Therefore, urban systems around the world need to take a further step into the 21st century by accepting crises as a new reality and finding strategies to function during these disturbances (Samuelsson et al., 2020). However, while addressing directly this unexpected global experience of COVID-19, any research should not forget the broader and more durable pandemic already occurring such as climate change. Indeed, both emergences are exposing our urban systems to vulnerability and long-term impacts, at all scale-level (Banai, 2020). Therefore, they both call for a reconfiguration of urban system, by a review of many urban policies, features and functions.

Evolutionary resilience approach can drive this process, encouraging new ways to "adapt to the new normal" and learn lessons from the crisis. Furthermore, in coherence with the Panarchy model of adaptive cycle, resilience perspective can help to see COVID-19 as an opportunity to "demonstrate creativity and flexibility" (Lopez, 2020). In a nutshell, this approach can determine the ability of a city to survive and recover from a crisis and for this reason, it is important to stress its role among the urban priorities. Finally, it has to be said that mentioning climate change in this context is crucial to underline the awareness of the topic-weight in terms of long-term urban perspectives and also to point out the need to find transversal solutions for urban forms. That clarified, however, in terms of crisis-experience of the related diffusion-process, the current work will address the Coronavirus pandemic and its issues, with specific link to density and population size role.

2.5.1 The pandemic crisis in the thesis context

This section aims to provide a more detailed view on a single case of crisis, that within this context corresponds with an unexpected phenomenon impacted at global level. More in particular, the attention will turn to the outbreak of Coronavirus disease between 2019 and

2020, as it has created a global health crisis that has had a great and **deep impact on the way we perceive our world**, our cities and our everyday lives (see Chapter 1 – "1.2.2 Setting the scene" section, to read more in detail about its narrative and practical evolution). In urban contexts, not only the rate of contagion and transmissions threatens our lifestyle and sense of protection, but the safety measures put in place to limit the spread of the virus also require new ideas to manage, design and plan the spatial system. Moreover, because contagion may progressively become a long-term or chronic threat, strategies to adapt urban contexts accordingly are becoming a salient request for academies and professionals (Viel, 2020).

With this in mind, this section introduces from a theoretical perspective the phenomenon analysed, while linking some of its aspects and impact to the previous concepts of complexity, urban system theory, diffusion process, and resilience.

In a Newtonian world, any action provokes predictable reactions, very linear and predictable. But today's complex systems are demonstrating how environmental, social, political and economic dimensions are constantly changing and influencing each other's unpredictably. Thus, in such a world, our humanized world, even a small change can be transferred and amplified by the huge connectivity of the system and its networks (Hynes et al., 2020), having a lot of consequences in different times, scales and places. In few months, since it became popular among people, coronavirus COVID-19 has firmly entered in our lives globally. As previously explained, when infections spread like a wave across continents and global populations, they provoke pandemics, from the Greek pan ("all") and demos ("people"), "prevalent over a whole country or the world". However, pandemics themselves are relatively rare. In modern history, only a few pathogens have been able to cause them: Yersinia pestis, originating the bubonic plague; variola, causing smallpox; influenza A; HIV; and cholera (Shah, 2016). Again this time: no matter where we live, the continuous news about its spread and measures adopted against it are observed with constant attention globally, exactly as it was overlapping rules of contagion, network, hierarchy and waterfall simultaneously (Haggett, 2001). With an estimated 90% of all recorded COVID-19 positive cases, urban areas are the epicentres of the pandemic (UN, 2020). Indeed, the concentration of population as well as global and local interconnectivity make them intensely vulnerable to the virus diffusion. For many cities, the COVID-19 emergency has expanded from a health crisis to a wider crisis of urban access, urban equity, finance, safety, joblessness, housing, public services, infrastructure and transport. Some of the impacts of the virus are still being understood, but it seems already clear that this disease will leave a sign on cities, physically and socially, whose echo will survive for generations (Van den Berg, 2020). Undoubtedly, the COVID-19 pandemic has shed light on the architecture of urbanism, highlighting strengths and vulnerabilities of the urban system (Banai, 2020). The pandemic-period addressed by this work tells also about extraordinary restrictions in the use of several places worldwide (Honey-Roses et al., 2020). Progressively, from the beginning of the virus-diffusion, half of global population has been asked or forced to stay at home or limit movements in public areas (Sandford, 2020), and in most places a second infection-wave has then occurred (and a third will probably follow, and so on). In the heart of the COVID-19 crisis, we feel to have lost our familiar, vibrant and social ways of being citizens.

Therefore, it is natural that several disciplines make it a central topic of their work, researches and projects. Journalists, planners, architects, designers and landscape experts are already reasoning about how this crisis will transform our relationship with urban space and perception. This interest sets a previously unknown challenge to both academics and professionals, as there is still little information about this coronavirus, and reliable data are evolving, and sometimes even hard to be found and clearly distinguished from rumours. Indeed, for the past decades, most of studies intersecting planning, design and public health have focused mainly on chronic disease, hazards, disasters and the vulnerable, and less on infectious diseases. Chronic illnesses have dominated the scene among the urban developing world, also considering the increasing worldwide leading causes of death in last years (ischaemic heart disease at first, followed by stroke, lower respiratory infections, chronic obstructive lung disease, and diarrhoeal diseases) (Neiderud, 2015). But the current pandemic crisis brings the **need to plan and design also for infectious diseases** and not only in low-income countries, raising important questions for future research, debates and practices (Forsyth, 2020). In a nutshell, this experience requires a **rethinking of the urban environment and system**, through a progressive integration of complex theories, resilient concepts and system perspective in urban and spatial planning. This integration will assume even more weight when focusing directly on the two urban features chosen for this study and with the results' analysis.

Evidently, in such a situation, the attention on cities becomes central as if from one side they are home for most of us, within this context they represent one of the main hotspots for the spread of the infectious disease. This condition inhibits our "normal urban life" for a period of months, not weeks, probably leaving permanent signs in the long-term. Furthermore, the pandemic condition has revealed considerable gaps in public space accessibility, design, management, flexibility, maintenance and connectivity (UN Women, 2020). Thus, there is reason to address the pandemic also from the point of view of urbanism, urban planning, architecture and the built-environment. Undoubtedly, the way to plan our cities has always reflected the prevailing cultural and technological trends and even major changes of a certain time in history. Notably, after the cholera epidemics of 19th century, modern urban sanitation systems were introduced in most of cities. Similarly, housing regulations around light and air were introduced to contain respiratory diseases in overpopulated slums in Europe during industrialization. More recently, digitalization and data have changed the way we explore cities and how we make new connections and discover new things, places, people, events and so on. In history, disease outbreaks have forced innovations in urban planning and design (Peters, 2020). The same may happen with this pandemic crisis, whose impacts may radically change the way we plan and perceive cities, as well as confirm some urban models already in place.

The perspective to guide this process should include both the physical and non-physical aspects of our cities, addressing respectively from one side the urban form, infrastructure, land use, access and environmental components, while on the other focusing on the sociocultural, economic and political dimensions (Lak et al., 2020). In this regard, to some observers, there are increasing reasons to look back at historic crisis as moments for drastic urban change. But for others, more optimistic, urban history may have more in common with continuity through crisis than about radical transformation (Klaus, 2020). In fact, **urban planning is a "long game"** in which change is gradual and effects of past decisions take time to overcome (Holland, 2020) As a prove, a couple of historical events of the last century as the Great Depression and World War II, demonstrates that despite great dynamics of poverty, inequalities, violence and international relations for the next fifty years, the urban trend did not change its overall trajectory. The same can be observed more recently, with the financial crisis of 2008 and 2009: the Great Recession took the global economy down but failed to radically transform urban areas. These samples of historical inertia in urban spaces highlight that, especially at higher scales, changes in the built environment require time to happen (in contrast with the rapidity by which more dynamic phenomena related to events/objects happen). And sometimes, urban space tends more to adapt than others, while it shapes new forms and functions.

This reaction adds further uncertainty about how **COVID-19 will impact future urban space, functions and perceptions**. Despite the growing interest of many scholars and public observers on these important topics, the debate is just emerging. The main questions arising will highlight firstly the need to understand, considering that the contagion-risk may become a long-term and chronic threat, which urban criteria might facilitate the mainstreaming of health criteria into the design of post-pandemic cities and which of them may improve the resilience of the urban system. Another issue aims to understand if we need new typologies of urban space, both public and private, functions and practices in the post-pandemic cities. In fact, the impacts of COVID-19 on our lives may impose a breaking moment in our practices, values and approaches to the city. Thirdly, reflections are needed also to highlight which urban properties have been particularly exposed to the spread of the virus during the outbreak and if the temporary transformations observed along the crisis will introduce more permanent changes. These reflections may link to several disciplines, but in this case will mainly consider the planning dimension. Finally, further thoughts will point out how our perception of urban space will change, and which spatial qualities will influence the change more also after the crisis. In this sense, resilience concept may guide the new circumstances we live in.

In general, the experience of the COVID-19 crisis has prompt us **to see our cities differently**, sometimes wondering what we are doing here, pressed into crowded cities across the world. The changes shaking our social, cultural, economic and public spheres were considered immeasurable. But as already observed in our history, in this confusing scenario, the human tendency to blame the most evident characteristics (of places in this case) is very common and “obvious”, somehow. For these reasons and with all these premises then, the work now moves to the theories that, under a context of urban system facing crisis, in turn part of a diffusion-process, explore the possible links between population size and density in the COVID-19 outbreak.

2.6 Reasons to study the role of population size and density in time of COVID-19 crisis: finding a common ground

As previously introduced, evidences from literature suggest that the ecological method applied to natural systems can be also applied to artificial systems, as the metropolitan and urbanized ones. In these contexts, as presented above, a more dynamic and "processual" approach to urban settings is also adopted by the geographical "diffusion-theory" that integrates the idea of movement (of an innovation, an event, a virus, and so on) with the complex condition of socio-cultural, environmental, economic and commercial environments. This common approach points out the vulnerable condition of these artificial contexts to any sort of changes, especially those more unexpected, threatening and moving-rapidly.

However, when turning to a direct experience of stress like this one proposed, the tendency is to find direct responsibilities in place, sometimes forgetting the whole complicated condition of urban contexts. This is the case of population size and density, often blamed by first pandemic observers, politicians, journalists and media, to be responsible for the high numbers of cases and victims in urban areas. But rather than taking these assumptions for granted, and in the light of all what theories suggest, there is reason to sustain that the study of population-size-and-density role in this pandemic may integrate the vision of Holling and Goldberg and the Diffusion-Theory by Hägerstrand and Haggett to read complex systems reaction in this new health-emergency scenario:

Cities are epicentres of capital and creativity, designed along history to be occupied collectively. In this situation, the so-called "**system interaction**", which in turn favours the spatial diffusion process, is particularly encouraged by density and population size. However, this apparent "first responsibility" points out that an individual analysis on these two features will only be partial, as in these urban complex contexts many other components actually cover a role in favouring the physical move of a virus from a site towards a new one (Haggett, 2001).

History observation tells us that cities appeared thousands of years ago for economic and industrial reasons. They kept on growing also in the less tangible dimension of human social, cultural and spiritual needs. The deep notions of public spaces, shared housing, streets and green areas originated from cities promoted a sort of collective affirmation, a sense that people live this all together. This means that the so-called "**historical succession**", also traced by population size and density, has its roots in the past, from which then it built on present while indicating future trajectories. Hence, thanks also to population size and density, **urban settlements have become centers of opportunities and facilitated interactions**, increasing economy, societies and growth since ages, showing how "**spatial interlock**" has intensified through time following the idea that any quali-quantitative change at any point in space would have inevitably affected others somewhere else. In this sense, the movement of a virus in terms of diffusion suggests the representation of a pattern, meant as the "product" of the event-movements in space and time (Morrill, 1970). In this pattern, this "product" inevitably meets the features of population size and density and interacts with them in different ways, that may transform even more in the post-COVID-19 era. Not only, another interesting reason to study these two features together with the diffusion process of COVID-19 refers to the **non-linearity** we may expect after this crisis in urban terms: even in case, finally, of very small changes in these parameters, the consequences can actually cause great qualitative changes in the future planning, political, living and social behaviours.

All this to say that starting from the sad awareness that **pandemics are anti-urban** and press on our human desire for relationships, connections and movement (Kimmelman, 2020) while vanishing our impulse to congregate, the two selected feature can actually bring to a new understanding of the urban reaction to COVID-19 threat. Moreover, when understanding that the ongoing Coronavirus epidemic has already disproportionally altered our traditional urban life-style, it will probably come out once again the heterogenous nature of our cities. Indeed, the COVID-19 outbreak imposed the **"unnatural" concepts of social distancing, isolation and self-quarantine**, which appear quite distant-concepts from all the theories mentioned so far. Our immediate response of social distancing not only limits our central desire to interact but goes also against the way we have designed our cities, squares, streets and transport systems. All these elements have been designed to be used and animated collectively. Undoubtedly, today and especially in these pandemic months people have made great use of teleconferencing, social media and other forms of remote and digital interaction. Social distancing has led to an increase of virtual communities, to which many of us belong, in a way none could have imagined some generations ago. However, there is still a need to balance all this virtual with direct contacts and interpersonal exchanges. These new and simulated forms of interaction put cities and people at higher risks of recession, isolation, loneliness and so on. This unexpected condition makes clear that the Coronavirus will provoke – and is already provoking – profound effects also on today's built environment (Lubell, 2020).

In fact, beside the phenomena of moving in new suburbs and in the countryside, in last decades people have proved their intention to move back to cities, seen as epicentres of new capital, opportunities, networks and creativity. Therefore, in the light of all that, it is evident that the role of population size and density in this process can be crucial to deal with the current (and future) crisis. And resilience concept can be a possible lens through which reading the re-organization and re-formulation of urban environments in time of COVID-19 crisis. Concepts of "resisting capacity" and "recovering ability" can provide ways to classify factors at multiple urban scales, while enhancing resilience toward both Coronavirus risk and conventional natural disasters (Takewaki, 2020). The ongoing and prevailing condition of pandemic diffusion, quarantined or restricted living should be considered as an important input for reconsidering some of the existing knowledge, research, literature and praxis related to the organization of cities (Dhar, 2020). The experience of such a crisis should be an **occasion to think** about the organization and planning of our future cities and buildings.

In the light of these reasonings, this research sustains that cities can learn from history for how to better prepare for crisis (Samuelsson et al., 2020). The urban environments have repeatedly played a key role along this pandemic (as already demonstrated through history), either improving certain qualities already present either developing new ones. In the following and crucial session, the focus will finally shift on the role covered by the two features of population size and density in COVID-19 diffusion pattern, according to the first literature published on this topic so far. Section 7 can then be considered both as the point of connection between the previous theories, and also the core theoretical part of this Chapter.

2.7 Population size and density: their role in COVID-19 according to literature

The theories presented and the topics deepened so far create a solid framework to recognize how urban settings are vulnerable to this pandemic. Specifically, when addressing the vulnerability of urban contexts, most of the present debate and knowledge turns around the role covered by high population size and/or population density in rising urban exposure to infection. From the urban planners' perspective, the debate basically involves two dimensions of a modern city: the (population) size and the density[8]. Understanding how these two dimensions cover a role in the ongoing pandemic plague will provide practical lessons to the future of pandemic-resistant or resilient urban planning.

Spontaneously, it may seem quite logic that high population density should be linked to higher COVID-19 positive cases and death rate. Sigler et al. (2020) state that dense urban environments seem to offer **more opportunities to the virus-spread**. This is because a denser population could result in a higher extent of social mixing, and therefore raise the chance of virus transmission between individuals. Current dialogues on newspapers, TV and social media, public opinion and planning practice often blame density for the rapid spread of COVID-19 in many big cities, especially in American Big Cities as New York, identifying suburban living as the new and secret American "weapon" against the virus. In fact, the increase of Covid-19's impacts on urban density can be linked to the logical and understandable proximity between people and increased probability of interpersonal contacts (Jamshidi et al. 2020; Whittle & Diaz-Artiles 2020). All this led to a negative image of urban denser areas, considered as dangerous "hotspots" of the coronavirus in several contexts (New York City first, but also Los Angeles, and other compact European Cities or Metropolitan areas, as Madrid, Paris, Milan, London, etc.) (Banai, 2020), inducing some misjudgements on the role of density in urban contrast to pandemic. The discursive and frequent link made between globalisation, densification and the virus diffusion fostered an anti-urban sentiment, which was soon directed against specific groups and inhabitants of bigger cities, especially through social media (Boterman, 2020). In fact, among these recent dialogues, density is correlated with demography and other critical social factors like racial composition, ethnicity, age and income. "In the nascent stage of a pandemic[9] of unprecedented impact, it is difficult

[8] Both meant, within this research context, as two "permanent" features. In fact, as better explained in the text, these two variables can be considered as a "stable picture" of the case study, even though the crisis experience addresses (COVID-19) is quite dynamic. This contrast would be limited if the two variables were considered in their most dynamic version, such as the temporary density of people participating at certain mass-events (concerts, sport matches, etc.), or the temporal passage of population groups in some areas, etc. However, this type of information was not available when the research started and, mostly, it was presented in a clear and uniform way, nor clearly linked to the numbers (cases and deaths) of the pandemic.

[9] The nascent phase of a pandemic, as better explained in geographical terms by Haggett and Cliff (2006), may actually represent the so-called "Onset-phase" where a new virus, named "innovation", enters a new region

to make definitive conclusions about **why some places have suffered more from COVID-19 than others**" (CHPC, 2020). What is quite clear, at least, is that the diffusion will impact more rapidly at certain (local) scales and, on the contrary, will spread slower in wider contexts (national or international ones). In this section, after deep focus on the theories behind a crisis taking place (COVID-19 pandemic experience) in complex urban systems, the attention turns on two specific features which are part of this urbanized environment and against which several critics have immediately gone when trying to find early "responsibilities" for the rapid virus-diffusion and its tragic impacts.

Strangely, when addressing local scales to find reasons for higher virus impacts, the reported and debated evidence on the links between density and COVID-19 is often contrasting and inconclusive. Specifically, in several studies, there is no clear relationship between virus cases rates and the number of citizens living per square miles, underlining that residential population density is no a key factor of COVID-19's spread. In Hamidi et al. (2020), the most important findings of their study, addressing the impact of density on COVID-19 contagion and mortality rates for 913 US metropolitan counties, is that density is not related to confirmed virus rates and inversely related to confirmed virus death rates, also extending the control for other variables. The study basically did not find a significant relationship between density and COVID-19 infection and mortality rates. Indeed, when considering the number of deaths per capita, density appears to be poorly associated to COVID-19 mortality. Thus, it is mainly a general assumption that **high-density levels are related to higher rates of transmission**, infection and mortality (Hamidi et al., 2020). The same can be found in Boterman (2020), who did not observe relevant positive relationships between county density and infection rate in the Netherlands, which is usually densely populated and highly urbanized. Also in Lin et al. (2020), in China the linear relationship between population density and the COVID-19 spread rate disappeared progressively. Therefore, despite evidences suggest that population **density is no a major risk** factor for this infection, it has to be clarified that the interpretation of the density itself can assume different weights in limiting or favouring acceptable health conditions. In this critical context of an invisible virus, transmitted from person to person, when too many people share a home or a public space, and

where a vulnerable population is open to infection. Usually in this case, only a single place (or a limited group of locations) is involved and then, according to several factors, the virus may take different pathways, scales, speeds, and dynamics. See Section 3 for more details about this "wave-process".

collect living environments in institutional settings, the risk of infection spread could all plausibly increase. This data is confirmed by several studies (Table 1), investigating the impacts of socioeconomic and environmental factors on transmission rates of the infection. Despite different observations in terms of infection-period analysed and area observed, Qiu et al. (2020), and Cartenì et al., (2020) underlined that high-risk zones of Coronavirus transmission tend to occur in locations with higher population densities. This is explainable by the fact that measures of social distancing and isolation are more challenging in high-density areas that include more crowded spaces.

For all these reasons then, some urban-studies literature, when referring to general urban density, talk about "**trade-offs**", whose introduction may lead to rethink about the different meanings and roles covered by a more "physical density", by the concept/condition of crowding and the intensity of social contacts. In fact, assuming that COVID-19 diffusion is highly related to social exchanges, then it is logical to state that quantitative and "physical density" is no itself a good indicator to monitor contagions. Instead, some recent reflections (Small et al., 2020) pointed out that rather than density itself, when deepening the relationship between COVID-19 diffusion and urban space, it should be worth addressing socio-cultural forms, connectivity systems, infrastructures, and so on. These kinds of topics may lead to hypothesize that the metropolitan sociality is even closer to the distancing-policies than "rural sociality" (Lévy, 2020).

To introduce this concept though, it is useful to make some distinctions about the typologies of density suggested from literature and also considered throughout this analysis:

- Population density: the metric addressed in this study, that finally revealed not to be a key determinant on the COVID-19 spread, especially in the long-observations term (see Chapters below).
- Internal residential density, also known as "overcrowding" in housing metric: here addressed through average household and family size, that finally turned out to be positively correlated with higher rates of COVID-19 positivity at ZIP Code level. This kind of density, usually less addressed, refers to large numbers of people living together in housing units that were not designed to accommodate those numbers. In addition to the domestic dimension then, there may be added also the institutional settings density and the public spaces and workplace density, in order to make deeper reflections also on these crucial places. However,

information on these density-contexts are not available and to date, they can be indirectly addressed through the observation of positivity rates among essential working-categories.
In this sense, Sharifi (2018) makes a distinction between gross density and net density[10]: the first one refers to the ratio of people, households, or dwelling units to a given area (block, neighbourhood, city, etc.), while the second one is the ratio of people, households, or dwelling units in an area allocated to a specific land use (e.g. residential) (Dempsey et al. 2010).

Back when no one would have imagined this global emergency, Li et al.'s study on the relationship between density and epidemics (2018), highlights that possible relationships between population density and virus propagation and magnitude have appeared quite inconclusive, unless some further context-details are taken into consideration: in particular, they focused on the idea that at the beginning of the propagation of an epidemic, the already present percentage of "susceptibles" (people without a proper immunity) is a crucial factor, capable to provoke a strong epidemic increase, independently from the population density conditions ahead. This observation is actually coherent with the diffusion-theory contents reported above (mostly by Hägerstrand and Haggett) and with the several rules observable during diffusion-phenomena. Thus, there could be both a metropolitan and a rural context under the lens, since what influences the contagions more is the **concentration of these susceptible people**, who are understandably more vulnerable. Logically, Li et al. (2018) add, if then the transmission takes place through air or water, both intuition and mathematical modelling would indicate that such a propagation is facilitated by a higher population density. However, as stated also in that work, these assumptions can vary a lot according to the scale of interest, as confirmed by Haggett approach in diffusion-terms (2001). For instance, when considering the size of a building, the calculated population density could actually correspond with people's average social distance, and thus be itself a significant element to predict/understand contagions. In this sense, Park et al. (2020) investigated which kind of density has been more relevant for the spread of the virus and found that the density that matters in COVID-19 transmission was the internal population density, where aerosols and droplets accumulate more easily. As scale increases, extending to the administrative and political boundaries for instance, the value of the population density could refer to the

[10] In this study, due to the difficulty to get homogeneous data at metropolitan level about the net density, the so-called "gross density" will be considered, with specific focus on the situation in the US metropolitan county level.

distances between dwellings, or even between settlements, and may no longer reflect human-scaled social distances. In this sense, an interesting historical study developed by the US Bureau of the Census on 1918 abut influenza and pneumonia at the scale of US states (US Bureau of the Census, 1918) pointed out that no correlation could be recognised between the influenza death rate and state population density. In this study, the outcomes of a zoom on "certain general statistical aspects of the 1918 Epidemic in American Cities" (further developed in the Public Health Reports in 1919) concluded that for 39 large US cities, no correlation emerged between the influenza outbreak and the population density. However, the researchers pointed out the higher possibility to get infected in cities, considering the larger number of occasions to meet people.

Moving to other spatial levels, Wheaton and Thompson (2020) addressed COVID-19 at two different scales – US counties and Metropolitan Areas (MSAs) along the first 70 days of pandemic emergency (end of March 2020). Interestingly, they found that population density is never significant, at least at the average MSA level, while had an intense impact at the county level where also other literature confirms that at the early stage of the pandemic, density was more influential then later on (the county unit is a much smaller geographical boundary compared to MSAs). In fact, as stated by Mercker et al. (2020) observing COVID-19 trends in Germany, the virus follows different spatio-temporal scenarios, and this is supported by the influence of several features like density, whose effect on COVID-19 contagion declined from the later phase of the first pandemic wave. Wong and Li (2020) added that at the US county level, population density covers an influential positive role in spreading the virus especially when combined with vulnerable population subgroups. However, they precise, although counties with high densities are expected to produce a higher number of cases, in reality the high density counties may in turn see different internal situations occurring in their neighbourhoods. For instance, in one of the first counties having confirmed cases – Saline County, Arkansas – there was a relatively low density, but deepening on a specific neighbour of its capital, Little Rock, they found very high-density levels at neighbourhood scale and then understood the situation. On the other side, it should be noted that global cities characterised by a high density and a low number of cases per residents, such as Singapore, Seoul (South Korea), Shanghai (China) or Hanoi (Vietnam), turned also to be the most prone to adopt rigorous testing-and-tracing policies (Fang & Wahba 2020). The perceived vulnerability of these places, and their past experiences of the "severe acute respiratory syndrome" (named "SARS") outbreak, covered a key role in a faster and more widespread reaction. Thus, the spatial models can explain cases-rise in counties with low population density by looking at their neighbourhood scales characterised by higher density levels. These conditions are particularly in line with the different behaviours characterizing the expansion process, at least in theory, and integrating: contagion, network, hierarchies and waterfall effects, according to different directions, speeds and scales. Another aspect to keep in mind, pointed out by Amdaoud et al. (2020) and usually omitted in the early stage of data-recording and observations, is the influence of governance styles and structures, whose roles were actually crucial in the regulation of human activities, access to healthcare and resources-mobilisation. The following table collects the selected and overmentioned papers and summarises their key findings about the observed impact of urban density on the number of reported COVID-19 cases and deaths. It points out also the divergence between studies about this topic. Many authors do not consider the significant effects of population density on COVID-19. Those authors who measure a relevant impact may observe a positive or a negative influence on the disease when increasing urban density, according to the dependent variable adopted (number of cases and number of deaths). From a paper to another, the statistical method used in the different studies vary. The information collected in Table 1 are based in most cases on the original authors' own conclusions. Most analyses considered $p < 0.05$ as a minimum threshold for significance. The table highlights also that there are several differences among studies focusing on the same topic of density related to COVID-19 cases and deaths.

Table 1 - Literature review on the observed effects of urban density on COVID-19 at different scales.

Reference	**Impact of urban density on the n. of reported COVID-19 cases**	**Impact of urban density on the n. of COVID-19 death**	**Definition of the concept of density**	**Unit of analysis**
Amdaoud et al. (2020)	Not considered	n.s.	N.inhab./km^2	377 EU regions in 28 countries
Angel et al. (2020)	+	n.s.	Share of the pop. living at high density (> 10,000 persons per square	US Metropolitan Statistical Areas

			mile)	
Boterman (2020)	n.s.	n.s.	Share of the pop. living in high densities (> 1500 people/km^2)	Dutch municipalities
Cartenì et al. (2020)	+	Not considered	N. of inhab./km^2 in the capital of the region	Italian regions (20)
Fang & Whaba (2020)	–	Not considered	N.of inhab./km^2	284 Chinese cities (not considering cities from Wuhan)
Feng et al. (2020)	+	Not considered	Tot persons per pixel (500 × 500 m) (www.worldpop.org)	Urban cells (resol. of 500 m × 500 m) in China
Hamidi et al. (2020)	n.s.	–	(N. of inhabitants + number of jobs) per square mile	913 counties of US metropolitan areas
Jamshidi et al. (2020)	+	Not considered	Urban pop./urban area (km^2)	All US counties (3006)
Lin et al. (2020)	+	Not considered	N. of inhab./km^2	16 provinces and four municipalities of China
Mercker et al. (2020)	–	Not considered	N. of inhab./km^2	402 existing administrative districts (ADs) in Germany
Park et al. (2020)	n.s.	Not considered	N. of workers (concentration in the call center)	A call-center with 216 employees in South Korea
Qiu et al. (2020)	–	Not considered	N. of inhab./km^2	288 Chinese cities, excluding cities in Hubei province
Rodriguez-Villamizar et al. (2020)	Not considered	n.s.	N. of inhab./km^2	772 Columbian municipalities
Sigler et al. (2020)	+	Not considered	N. of inhab./km^2	84 countries
	–	Maximum urban density		
Wheaton and Thompson (2020)	–	Not considered	N. of inhab./km^2	US Metropolitan Statistical Areas (MSAs)

Whittle & Diaz-Artiles (2020)	+	Not considered	N. of inhab./km^2	New York City zip codes with identified cases
Wong and Li (2020)	+	+	N. of inhab./km^2	3.144 US counties (excluding Puerto Rico)
Zhang & Schwartz (2020)	+	+	N. of inhab./km^2	1.624 US counties with 16 or more cases

Note:
± →Positive/negative and significant correlation between urban density and number of COVID-19 cases/deaths;
n.s. → non-significant correlation.

It is important to highlight that the analysis-scale largely varies between different studies, from the urban and supra-territorial level to the province or cross-national scales. Indeed, while some studies are focused on cities, others would consider entire politico-administrative units, as the Italian regions, aggregating urban and rural areas.

On these bases, researchers should interrogate whether large-scale population density is still appropriate for representing the extent of social mixing and coming into contact for broad regions. As a result, the influence of population density on COVID-19 spread might vary accordingly with specific scales, conditions and time.

On the other hand, also population size would potentially cover a role in a given area, influencing the **extent of social mixing**, but in a different way. Indeed, according to the urban planning theory, agglomeration forms the cities (Glaeser and Gottlieb, 2009), which then "feed" human societies. Theoretically then, a larger population size would favour a wealthier and more solid human settlement, producing better services and supporting interpersonal interactions and connections. Read in another way, in larger settlements there are usually more chances for interpersonal contacts, and in a context of pandemic emergency, this condition could provoke higher risk of infection. In parallel, however, when the population size increases, there is reason to also consider the easier development of health service capacity of an urban area, which, in turn, could lower down the risk of getting infected. Therefore, considering the multiple and complicated effects that the development of population size could produce on the other variables in place, it is hard to arrive at an immovable conclusion about the role played by population size on COVID-19 severity in a certain region.

In this research context, it has to be clarified that when analysing the potential impact of population size on the pandemic diffusion, the proposition is not that population is responsible to "add volume" to any concentrations of Coronavirus cases or deaths. Instead, the goal is to understand the role of population size, as well as of density, in favouring or limiting the virus circulation in a certain unit of area. In fact, in this sense it is interesting to understand the extent of social interactions and mixing leading to infection in contexts characterised by different population sizes.

That said, there is no reason to be surprised about the existing literature debating also on the effects of population size in the pandemic context.

As previously shown, most of the published research outcomes support the thesis that population density provokes an improvement in local COVID-19 case and death rate, without focusing on the effect of population size. A recent study by researchers at the Johns Hopkins Bloomberg School of Public Health in the US states that the infection rate is not related to population density, whereas death rate is inversely linked to it (Dong, 2020). Moving to another context, Bhadra et al. (2020), who pointed out the "no-surprising" result of positive association between urban population density and the COVID-19 severity in a state of India. This is related to the great possibility of social interaction and mixing in highly populated areas, where poverty and social differences are evident factors. But still remaining in India, Rajkumar R. P. (2020) highlighted **no significant association** between population density and fatality levels because the unequal distribution and accessibility of health care services in the Country are very heterogeneous. These outcomes, sometimes in clear contrast to the findings by the researchers at the Johns Hopkins Bloomberg School of Public Health, London school of economics, and IZA—Institute of Labour Economics, are mainly related to the great difference in the living conditions of US and Indian people, which may reflect different behaviour of the population in the two countries.

In another study and in line with the overmentioned Hamidi et al. (2020), Carozzi (2020) found that **density has influenced the timing of the outbreak** in each US county, specifying that denser locations were more likely to have an early outbreak (also stated by Feng et al., 2020 in a Chinese study based on the Wuhan area). They demonstrated that population density can impact on the Coronavirus time of circulation through higher connectedness between denser areas. However, in general Carozzi's results did not find evidence that population density is linked with Coronavirus cases and deaths and, even more interestingly, they found positive association with social distancing behaviours (Carozzi, 2020). In line with the effects of social conducts, Barak et al. (2020) did not find main effects for density in Israeli cities, but he highlighted a conditional effect for density when taking urban socio-political attributes into account. Interestingly in fact, he opened the study with the awareness that current debates identify population density, especially in urban context, as a major catalyst for COVID-19 spread. But moving then to the observation of 271 Israel localities during the first three months of the pandemic, in a Country where more than the 90% of the population is urban, they found that rather than density, policies cover a critical effect in COVID-19 spread. It can be observed that compliance plays a crucial role at urban level and density's influence on contagions depends on urban political flows. Angel and Blei (2020), however, overturn the statement sustaining that COVID-19 thrives in larger cities instead of denser ones in the US. In their study, they argued that larger cities have more than their share of cases and deaths partly because the larger the city, the larger the quantity of possible interactions among its citizens. And they see this larger number, rather than the overall average proximity of people to each other— usually expressed through the average density in the city—to account for that larger virus distribution. In fact, they continue, when it pertains to COVID-19 cases and deaths, denser metropolitan areas appear to be more capable to limit their numbers than more populated areas do. Thus, despite the few attention turned to population size, also in terms of literature, in those few cases where it is investigated, it proved to be an actual influencer.

From these observations, it is possible to observe a distribution pattern about the existing perspectives for the researchers involved. In short, it is possible to state that studies focusing on Chinese cities before 2020 spring (Sun et al., 2020) mostly rejected to blame density for the COVID-19 spread, rather suggesting that **lockdown policies** of China effectively limited COVID-19 circulation rapidity. However, later studies (Han & Jia, 2020 and Zhu et al., 2020) pointed out density's positive relationship with COVID-19 spread. This situation was particularly critical in urban contexts characterised by higher population density than in rural ones, where density was lower. From the analysis on other South Asian (Biswas et al., 2021) and European countries (Yaylali, 2020), the results almost agree on the positive influence of population size and density on COVID-19 threat, both in terms of positive cases and death rate. Back to the US however, the studies point out quite different scenarios and, interestingly, usually highlight **the role of the policies in place** in influencing the virus distribution (Hamidi, 2020 and Carozzi, 2020). In a nutshell, the overall trend usually weights population size over density in the contagion influence, sometimes even asserting that density was not influential at all. Nonetheless, later studies gradually pointed out that both population density and size covered an important role in increasing COVID-19 circulation. At this point, it becomes interesting to understand the causes of the differences among the overmentioned results. Several factors could actually be cited.

Firstly and logically, it is possible that **data from different temporal phases of the pandemic could produce different results**. This behaviour is also observed by the expansion process introduced by Haggett in his studies on the Diffusion (2001), and then improved by the idea of "wave" where the virus "matures" through time (Haggett and Cliff, 2006). Reflecting on the very early stages of the pandemic, when a large number of virus carriers and incubating cases were not well identified, and when the transmissibility-level and virulency of the virus were not yet recognized by the public, the extent of social interaction and mixing could be as much as usual. As a result, the effects of density and population size on social mixing were quite strong and followed established patterns, at least for a while, and in turn largely impacted on COVID-19 growth. Passing to the later phases of the emergency, however, when the governments started to introduce policies and administrative measures to protect citizens, and when in parallel also the mass media worked to constantly advocate the importance of using the PPE (personal protective equipment) and of social distancing, the deepness of social interactions decreased a lot as time went by, and therefore, the effects of density became also smaller on COVID-19 growth.

Secondly, **political factors** have to be considered, including the local beliefs about the virus and the more local policy reactions related to COVID-19 (Nir, 2020), as they also affected population size and density's influence on the number of COVID-19 cases in many countries, including Europe and the United States. On one side, in line with specific economic policies, the prevalent attitude towards pandemic may vary between political parties, which may behave differently during the pandemic, according to the party supported. On another one, the state or county measures aiming at controlling the viral diffusion, for instance, "Shelter in Place Orders" and "Mask Requirement in Close and Public Spaces", will not only modify the extent of social interaction mixing at a specific level of density and population size but also reduce the transmissibility of the virus at a fixed limit of social mixing. Both measures will further alter the impact of density and population size on COVID-19.

Thirdly, another important aspect relates to the **cultural context** that can also influence people's choices and behaviours during the pandemic. This kind of influence can be noticed in different amounts of social interaction and mixing. The cultural context is different from the political principles and belief in the sense that it does not change considerably during the pandemic, and would hardly create temporal impacts on COVID-19 time-series data collections about reported cases or deaths. However, this is a crucial factor to consider when interpreting different research results coming from diverse countries with focus on pandemic influencing factors. For instance, the use of masks and face coverings is usually welcomed and generally considered fashionable in China and Japan (Beglin, 2020) even if there is not an on-going pandemic. In fact, already for decades, when someone in Tokyo gets sick and needs to travel, he/she wears a mask. The same can be observed in South Korea, China, Thailand, and Malaysia. The reason is so simple but also astonishing from other points of view: they usually wear masks when they are sick to protect others. Thus, when Coronavirus broke out and Eastern counties were advised to wear masks, most Chinese and Japanese people felt more comfortable and less reluctant to follow the guidance. On the other side of the ocean, in contrast American people did not enjoy or feel familiar to cover their faces routinely. Thus, they were not as active as Eastern people in respecting the mask requirement guidance. This trend is simply one dimension of how the cultural difference might provoke the effect of density on COVID-19 to change.

To conclude, we could hypothesize that the effects of density on COVID-19 are actually highly related to several regional attributes away from demographic and socio-economic conditions – such as the temporal phase of the pandemic, the policies in place, and the cultural environment. Or read in another way, without considering these regional attributes, the net density-impact on COVID-19 spread could hardly be effectively examined or evaluated.

Nevertheless, in most of the existing researches over-mentioned, there is a **lack of socio-economic and political indicators and pandemic indicators**, which can potentially connect the results to their political, social, economic, cultural, and time context, making them more coherent with the real interpretation of each condition.

In this sense, as previously introduced, it is interesting to integrate this intricate view with that of diffusion-process, urban complexity and resilience approach, in a way that allows to progressively consider urban systems as complex entities where, among the others, the element of change is considered an integrated system-element and where resilience concept can represent a perspective through which reading and understanding these kinds of phenomena. In the following important chapter, the work shifts to the real investigation on pandemic-behaviour and urban characteristics (from population ones to socio-economics). Among other urban features then, a quantitative analysis will be developed and processed in order to understand how population size and density weighted in the diffusion process and if they can be considered influential in the virus-outbreak dynamics when applied to a specific case study (already introduced in Chapter 1).

CHAPTER 3

METHODOLOGY

> *A case study is an empirical inquiry that investigates a contemporary phenomenon in depth and within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident and the investigator has little control over events.*
>
> Yin, 1989 – Case study research: Design and methods

3.1 Methodology approach

This PhD thesis is an **exploratory sequential mixed method that combines qualitative and quantitative data collection and analysis, in a phases-sequence** (Creswell and Plano Clark, 2011). This means that in the first phase, the work focuses on the collection and analysis of qualitative data and then is followed by the quantitative phase, which could correspond with several forms of quantitative data collection. Thus, more explicitly, the qualitative part provides critical issues to develop specific research topics for the quantitative part, which can involve a survey, a data collection, a data mathematical elaboration, a questionnaire, and so on.

According to Edmonds and Kennedy (2017), the rationale behind this approach is to firstly explore a topic before identifying those variables that need to be analysed and measured. In other words, this design can be seen as a template that is employed in a specific situation, but each situation may apply this design differently.

The qualitative part is called "**exploratory**" because it can be driven both by data and by literature review, so as to better understand the research gaps and problems. This step explains why quantitative **data collection is "postponed"** in the process, as the qualitative phase adds conceptual weights before passing to the numbers, calculates, surveys, and so on. The qualitative analysis part involves the identification of significant theories and quotations, able to introduce and develop greater themes and discussions. Then, when moving from qualitative to quantitative analysis, the attention turns on variables, items, measurement categories and closed questions, keeping a logical relationship with the qualitative part. In fact, in mixed method research, the connective points between qualitative and quantitative elements are called "points of interface" by Creswell and Plano Clark (2018). In this exploratory sequential mixed method, this edge is represented by the qualitative and quantitative phases and also by the general prioritization of the qualitative components. This research-development of the exploratory sequential design can be described QUAL→ quant (Creswell and Plano Clark, 2018).

More specifically, this work is an **inter-disciplinary research** that tries to develop the theoretical field of urban science through a practical crisis experience observed within a precise case study, and explores the possible implications for planning. Furthermore, with the focus on the COVID-19 crisis, it also revolves around the need to explore the interconnected field of crisis experience, city science and public health knowledge in a specific and representative local context, which may guide further similar studies anywhere else.

Following Creswell et al. (2003) and integrating the main thesis contents, this work can be classified as a mixed method research, since:

- It collects "mixed forms" of data, from qualitative open-ended information and quantitative data;
- It tries to explain some concepts associated with qualitative research, while also using variables and factors available in quantitative research and processing;
- It faces statements that can both be explored more in depth with reflections and subsequent observations, and also be analysed through data analysis and connections;
- It follows separated steps of data analysis: first the qualitative explorations and early findings of the qualitative phase from literature, second the main results of quantitative data analysis from literature and databases, and finally an integration and examination of these two parts demonstrates that the qualitative early part is better understood, argued and discussed with the pragmatic values of the quantitative results;
  It ends with a final discussion that highlights the main qualitative thematic findings supported by the quantitative analytical results.

Based on these traits, the thesis integrates qualitative and quantitative research, following the accepted issue promoted by Greene and Caracelli (1997) that "*mixing different types of methods can strengthen a study*" (Creswell et al., 2003). An accepted and recognized definition of mixed methods study states that: such approach includes the collection or analysis of both qualitative and quantitative data in the same study, where **data are collected sequentially or concurrently**, then follow a priority, and support the integration of data at one or more stages along the research process (Creswell et al., 2003).

As previously mentioned, a **sequential exploratory design** can be recognized here since two main phases can be distinguished (as stated also in Figure 1), with the priority given in this context to the first one. Within this setting, the research design method is characterized by a starting phase of qualitative data collection, analysis and early discussion, followed then by a phase of quantitative data collection, analysis and first results comment, based on a real case study. Thus, the priority turns to the qualitative aspect of the study. Finally, the outcomes of these two phases are integrated in the so-called "**interpretation phase**", where the main theoretical findings are read through the lens of quantitative analysis and more deeply and critically explained. In a nutshell, it can be said that the goal of this methodology is to use quantitative facts and findings to favour the interpretation of qualitative results and statements. Moreover, another purpose of this design is to explore a phenomenon widely (Creswell et al., 2003). Suitable to the current research topic, Morse (1991) recognizes that this approach is particularly appropriate when understanding and determining the distribution of a phenomenon within a selected population.

Understandably then, the sequential exploratory design requires a relevant amount of time to complete both data collection and analysis phases, since in some passages it may be difficult for the researcher to make direct and immediate connections from the qualitative analysis to the following quantitative data collection (Creswell et al., 2003).

3.1.2 Characteristics of the "Case Study Research"

Before deepening on the US Metropolitan Counties crisis experience of COVID-19 and starting from the presentation of the sequential exploratory design, where the quantitative component covers a crucial role in the understanding of the topic addressed, it is important to describe the traits, strengths and weaknesses of the "case study research approaches" in urban design research, both in general and also in relation to the current work.

The so-called "Case Study Research" (CSR) is a typology of empirical research strategy which can be often found in urban and architectural works (Groat and Wang, 2013). Through profound investigation of a series of situations in real life contexts, CSR allows to create knowledge on a system. In Yin's perspective (1994), the advantages of CSR are evident when exploring little-understood processes or activities or "*when the boundaries between phenomenon and context are not clearly evident*" (p: 13). This latter aspect characterizes in particularly complex socio-ecological systems as urban systems, where it is not possible nor required to isolate the body of the investigation from other issues and dynamics taking place in its context. Indeed, the case study research opens to a systematic study of the spatial effects of conditions, decisions and processes driven at multiple levels (political, societal, economic, environmental,…) to deal with crisis and unexpected disturbance. Moreover, in comparison with other research approaches, CSR can count on several methodological advantages, as the possibility to rely on multiple categories of evidences, data collection procedures and analytical methods to answer specific research questions. Thus, it is widely accepted as the appropriate choice in architectural and design disciplines to analyse historical and contemporary phenomena and spatial contexts (Groat and Wang, 2013).

Nonetheless, developing this approach can sometimes be very challenging, since there are no rules, nor codified procedures for organizing and leading the analysis and then for distributing the results (Yin, 1994), as these parts mostly depend on the objective of the investigation itself, specific traits of the case study and availability and quality of data. This trouble further increases when data are heterogeneous (quantitative, qualitative, etc) and several typologies of analytical techniques co-exist. Thus, CSR requires that some choices have to be made because, if not properly argued, explained and organized, the research outcomes may be negatively affected in terms of reliability and replicability. In order to avoid this, it is strictly important that every step applied to the case study, from the methodological aspects to the motivations behind the selection of the case, data and assessment techniques, as well as results interpretation, is addressed in a comprehensive and rigorous way.

As previously explained, the case study scale adopted in this work has to do with the 3.143 US counties and, more specifically, only with the so-called "Metropolitan" ones (923 units). As already explained, this decision has to do with the interest in highly populated areas where the concentration of people and activities is usually higher. In the United States, the metropolitan counties are defined by the US Office of Management and Budget (OMB) and used by the Census Bureau and other federal government agencies for statistical reasons (Nussle, 2008). Metro and non-metro status was defined by the Office of Management and Budget (OMB) in February 2013. Urban/rural classification type is based on the 2013 National Center for Health Statistics Urban-Rural Classification Scheme for Counties[11]. In terms of statistics and space, a metropolitan statistical area (MSA) is a geographical region with a relatively high population density at its core and close economic ties throughout that area. According to the "2020 Standards for Delineating Core Based Statistical Areas", the general concept from which the distinction between Metropolitan (and micropolitan or rural) originates is a core based statistical area (CBSA) containing a large population nucleus, or urban area, and adjacent communities having a high degree of integration with that nucleus. These premises and definitions made, despite specific differences on the field, the spatial base on which starting the analysis more structured. The following section adds the details guiding the variables-selection, for both independent and dependent analysis-features.

3.2 The background for selecting the variables

As written before, these crisis phenomena have to be read in a broader and more complex context, where several features cover a role in the relationship standing between density/population size and COVID-19 variables. Despite Carozzi et al. (2020) consider 2016 election data as one of the variables in place when understanding COVID-19 local behaviour, it has been outdated in reproducing a county's political attitude concerning the 2020 pandemic. Hamidi et al. (2020) consider "whether or not the county had introduced the Shelter-in-Place Policy" as a variable, without considering that all these policies remained active for different periods. Another possibility, observed also in other studies, is to focus exclusively on population size and density's impact on Coronavirus spread, integrating also

[11] More information about the "2013 NCHS Urban–Rural Classification Scheme for Counties" are accessible at: https://www.cdc.gov/nchs/data/series/sr_02/sr02_166.pdf (last access: August 2022)

other socio-economic variables, but without considering any variables related to policy.

In this context of research, considering the interest in understanding the actual role of density and population size on COVID-19 in the US Metropolitan Counties, independently for the political preferences, the only variables considered in parallel are those describing the socio-economic conditions, independently from density and population size. The expectation about this integration is that the parallel understanding of the role covered by the other features, can clearly depict the role of density and population size in the expansion of the pandemic at the county level in the United States, while examining the weight of these two independent variables in determining COVID-19 rate.

To estimate the COVID-19 situation in each county, the dependent variables in this work correspond with the total number of COVID-19 reported cases, the total identified accumulative deaths, and the total identified deaths per 100’000 people.

Nonetheless, as stated in several discussions and studies, the number of reported Coronavirus cases and identified deaths can point out several limitations in reporting COVID-19 real behaviour and distribution. On one side, the number of COVID-19 cases is largely dependent on the volume of tests carried out by the county, so that a greater reported amount does not automatically mean that the county really has a larger number of infected or more virus carriers. On another one, theoretically, the number of recognized COVID-19 deaths could be more easily associated with the hospital capacity than the real degree of COVID-19 spread, because the COVID-19 victims in record usually correspond with those that got hospitalized before death, while only some of the patients with severe COVID-19 symptoms actually got tested or went to hospital prior to death. Nonetheless, these two variables can be considered the best available predictable indicators for COVID-19 behaviour at the county level, since they do not count one person for several times, and their records actually began early since the pandemic has broken out. In contrast, the test positivity rate, despite many Asian studies considered it as an ideal indicator (Sun et al.,2020), cannot yet be considered a publicly available data source for the county-level of the United States from the Center of Disease Control (CDC) website. Moreover, the clinical reports about testing could only date back to August 2020, thus only for the second half of 2020 records, with limited information about the 14-day indicators involved. Even though several counties (and states) launched test-data-tracker projects and announced cumulatively tests by county, the sources of data and the calculation method were heterogeneous: some states and counties just summed the PCR tests and antigen tests volume sum from the CDC clinical reports, without considering the first half of the (crucial) year 2020; some states/counties only took in consideration the test volume from hospitals and clinics (federal and public), without collecting data from private entities. Additionally, earlier from calculating the positivity rate, some counties figured out the total number of people who got tested, while others calculated the sum of tests carried out. Interestingly, in some states and counties, it is possible to observe a clear rise of test-volume after the vaccinations entered into practice (thus from February/March 2021), also causing the on-site work requirements of regular tests. For instance, states like Georgia and Illinois actually collected most of their COVID-19 tests carried out in the central months of 2021. Therefore, considering this situation, the COVID-19 positivity rate presents several limitations that may influence the understanding of the COVID spread.

Nevertheless, to maximize the integrity of this study, these indicators were processed as dependent variables as stated above, despite the limitations of each. The sample size of the metropolitan county level, in order to make clear distinction among different contexts and to avoid potential ambiguity on COVID-19 mechanisms, divided the metro from non-metro counties. In line with other studies already focused on US COVID-19 issue at metropolitan level (Wheaton &Thompson, 2020; Angel and Alejandro, 2020; Carozzi, 2020; Haidi et al., 2020), this research tries to focus on the two overmentioned independent variables, in specific attention to the so-called "Delta wave" happened during the 2021 summer. Distinction between Metropolitan and Rural counties has been applied according to The Office of Management and Budget (OMB) (Table 2). In their statements and codes[12], it is possible to read that counties are defined as Metropolitan, Micropolitan, or Neither. As the Table 2 highlights, a Metro area includes a core urban area of minimum 50,000 population, while a Micro area contains an urban core of between 10,000 and 50,000 people. This definition refers to a threshold of population size of a county, and could also, to some extent, make distinctions about the socio-cultural backgrounds of the US counties. Such differences in the cultural dimension could probably result in how each factor may influence COVID-19 growth, and should be cautiously taken into consideration.

[12] HRSA – Health Resources & Services Administration: Defining Rural Population: https://www.hrsa.gov/rural-health/about-us/definition/index.html#:~:text=The%20Office%20of%20Management%20and%20Budget%20(OMB)%20designates%20counties%20as,but%20less%20than%2050%2C000)%20population (Accessed on June 21st 2022).

Table 2 - Distinction between Metropolitan and Rural counties applied according to The Office of Management and Budget (OMB).

How does OMB define rural?

Area or County	Rural or Not Rural
Metro area (urban core of 50.000 or more people)	Not rural
Micro area (urban core of 10.000 – 49.999 people)	Rural
Counties outside of Metro or Micro Areas	Rural

After the 2010 Census, the non-metro counties contained 46.2 million people, about 1% of the population and covered 72% of the land area of the country.

As previously stated, the dependent variables referred to COVID-19 behaviour have been collected at the US Metropolitan County level in parallel with a selection of independent variables, on the top of which population size and density can be found. The analytical methodology applied to put the independent and dependent variables in relationship is the multiple regression model, both with linear and log approaches. Along this analysis, the more interesting coefficients and p-values for the main independent variables were collected from different regression outputs, in order to understand their role in relation to the different dependent COVID-19 features. The coming sections describe the variable-selection process, with distinct focuses on independent and dependent ones.

3.3 Variables Selection

In the following two sections, the work deepens the empirical understanding of the crisis experience, working with two axes of indicators: the independent proxies of the metropolitan built environment, that basically describe several factors at the metropolitan county level, with specific focus on population density and size; and the COVID-19 variables (here described through: the cumulative number of positive cases in relation to tested people in each county, the cumulative number of deaths in each county and the cumulative number of deaths in each county per 100 k people). These proxies, either more or less tangible, can provide an overview on the physical and non-physical as well as on the built and socio-economic environments to face the COVID-19 crisis at county level. These data are particularly useful to clarify in terms of both methodology and contents, the meaning of these variables within this research.

3.3.1 Independent Variables Selection

In order to frame the analytical part of the research and clearly point out the effect of population density and size on COVID-19, the selection process of the independent variables in place, based on the existing literature, is highly crucial. First and foremost, considering the goal of the thesis, the two principal independent features are population size and density (here addressed at county level). In their support, further explanatory variables are added, covering other socio-economic and spatial dimensions that can potentially clarify the adjustments of the COVID-19 spread. In fact, to develop a broader understanding of the features influencing COVID-19 behaviour, it is useful to include both population and socio-economic characteristics. These metrics can provide an overview on the case study and when linked to others, can offer a more complete understanding of certain phenomena. Moreover, since pandemics have historically hit minorities and persons at the bottom of the socio-economic scale unequally, there is no doubt on the great sufferance of some people due to more risks-exposure, economic troubles, housing conditions and limited access to services (Wade, 2020; Sharifi and Khavarian-Garmsir, 2020). In this scenario, the rapid spread of Coronavirus has shed again lights on some of these problems, highlighting the close connection between the built environment and socio-economic problems and inequalities. Indeed, studying COVID-19 effects at urban-physical level relates to a combination of factors (that, in turn, influence the spatial diffusion of the virus in specific areas), starting from built-environment factors, mobility-habits, access to basic services, to housing condition, occupancy, precarious life-levels, and so on. Thus, the following identified proxies are meant to both materially and immaterially explain some traits of COVID-19 influencing impacts as well. Given that COVID-19 is impacting with no discriminations on every US County, part of the attention is then turned to observable indicators that explain for instance disparities in virus spread across US Metropolitan Counties. Within this context, indicators are provided by both GitHub repository and Bureau of Census (and Statistics). For each US County (no distinctions are done, in each original data collection, between Metro and Rural Counties – these distinctions will be provided successively by the author), the data bases contain information about population features, employment and unemployment rates, ethnicity profile, education attainment levels, commuting behaviours and average household size. They represent a fundamental source for this work. From this basis, the following identified proxies are meant to link the environmental profile with the COVID-19 behaviour as mentioned in Chapter 1. In details, here the independent variables selected:

- Number of population, so-called "**population size**" by metropolitan county (N): this data refers to the number of residents in each US County, according to the 2010 US Census.
- **Population density** by metropolitan county (N pop/sqm): this proxy relates to the quantity of people per square mile(sqm) in each county, relating the number of persons in each county according to the 2010 US Census and the total area in square miles.
- **Household size** (average) by metropolitan county (N): according to the American Community Survey (ACS), the "average household size" refers to the persons per household (according to data from U.S. Census Bureau's 2014 – 2018 American Community Survey) and is obtained by dividing the number of persons in households by the number of households. Average household size is rounded to the nearest hundredth (ACS, 2018). While the average household size for the US Metropolitan Counties is 2,6 residents (Census, 2010), looking at database, the US metropolitan county values range between 2 (Sumter County – Florida) and 3,9 (Starr County – Texas). This proxy is particularly interesting because, firstly, it can clearly highlight its relationship with COVID-19 diffusion and mortality, and secondly, it can introduce some deeper reflections on the housing conditions of some neighbourhoods, where probably further efforts in urban planning are needed. To add further information to this data, the features in place are divided into average household size, average household size occupied by owners, and average household size occupied by renters.
- **Commuting time** (mins) by metropolitan county (N): this proxy refers to the number of workers in commuting flows leaving from their residency places in each US metropolitan county, according to the 5-year American Community Survey, 2011-2015. Within this pandemic condition, it is useful to understand the percentage of people moving every day from their residence county to workplace county commuting flows and thus realize the level of exposure to the virus related to the time spent in travel. Nonetheless, this feature contains some limitations referred to the coexistence, under the same data, of several methods of transportation. Indeed, the ACS data

describe the most common method of transportation[13]. Therefore, if workers use more than a mode of transportation to get to work, they are invited to select the transportation method that was utilized for the highest distance travelled. This means that sometimes, there may be a lower estimate of public transit commuting if a worker drives a superior distance than she/he travels by public transit. Not only: with focus on more local scales, the application of less common transportation-modes, such as public transit by bus or metro, walking, bicycling, car sharing and so on, may be underestimated. This limitation will be then considered when interpreting results, as also suggested by the high margins of error pointed out in the original ACS datasets.

- **Income levels** (average) expressed in terms of median household income ($) by metropolitan county in 2019: this feature, highly cited in the growing literature of COVID-19 distribution (Lak et al., 2020; Maroko et al., 2020; Sharifi et al., 2020; Therese et al. 2020; Truong & Asare, 2021; Whittle and Diaz-Artiles, 2020), seems particularly influential in determining people's vulnerability to the infection risk of COVID-19. Not only, it seems that household incomes are related in opposite directions with a higher incidence of getting tested from wealthier people and with a lower likelihood, from them, that a test turns into a positive result. Moreover, it seems that low- and middle-income levels reduce the access to health services, insurance coverage and, in this context, also to the immediate application of proper measures to contrast the pandemic diffusion. These conditions can lead to an increase in COVID-19 positivity rate that can also highlight significant inequalities between close metropolitan counties.
- **Poverty levels**, expressed in terms of people of all ages in poverty (N) by metropolitan county in 2019 and according to the U.S. Department of Commerce, Bureau of the Census, Small Area Income and Poverty Estimates (SAIPE) Program. Similarly to the previous one, this feature, highly cited in the growing literature of COVID-19 distribution (Lak et al., 2020; Maroko et al., 2020; Sharifi et al., 2020; Therese et al. 2020; Truong & Asare, 2021; Whittle and Diaz-Artiles, 2020), seems

[13] More information about the methodology applied by the American Community Survey (ACS) can be found in the sample of questions proposed to people about where they work, how they get there, when they leave home, and how long it takes, so as to develop uniform statistics about commuting. Commuting/ Journey to Work – survey: https://www2.census.gov/programs-surveys/acs/about/qbyqfact/2016/JourneytoWork.pdf (last access: 26th August 2022)

particularly influential in determining people's vulnerability to the infection risk of COVID-19. In fact, as logic suggests, it seems that poverty, at all ages, increases the incidence of getting infected. Moreover, as already mentioned, lower poverty levels usually have lower access to health services, insurance coverage and, especially in this pandemic context, less rapid application of proper measures to contrast the pandemic spread.

- **Education levels** by metropolitan county (N - %), according to the educational attainment for adults aged 25 and older for the U.S., States, and counties, 1970-2019 (from the U.S. Census Bureau, 1970, 1980, 1990, 2000 Censuses of Population, and the 2015-19 American Community Survey 5-yr average county-level estimates). Despite the great availability of data about educational levels among citizens, the selection in this work considers exclusively two educational categories: on one side, adults (available in both numbers and percentage) with less than a high school diploma, from 2015-2019; on the other side, adults (available in both numbers and percentage) with a bachelor's degree or higher, again from 2015 to 2019. Also in this case, education can influence the Coronavirus spread, usually collecting more infections among lower educated people.
- **Ethnicity races** by metropolitan county (N), according to the National Bureau of Economic Research that collected population estimates for the 2000s and earlier. The original list of data actually collects several ethnicity races, living alone or in combination: White, Black and African American, Asian Native, American Indian and Alaska Native, and Native Hawaiian and other Pacific Islanders. However, in this case, since numbers of American Indian and Alaska Native, and Native Hawaiian and other Pacific Islanders are particularly limited (and thus, non-significant for the current research), the analysis decides to focus exclusively on White, Black and African American, Asian Native classes, which are more populated. In general, about the interest in racial structure, it can be said that how racial culture and behaviour influence the COVID-19 diffusion is still a relevant topic. For instance, as pointed out by Almagro and Orane-Hutchinson, the adherence to the shelter in place policy or the household average size are often related to the racial cluster, at any administrative level.

Among these features, the attention is mainly focused on population density and size, while the others can help to better understand the cumulative patterns of COVID-19 infection, among the most vulnerable variables. Moreover, while in this first step, every feature is worth attention, it has to be clarified that in the further steps of the quantitative analysis, some of them may be excluded from the interpretations and final results, being uninfluential or unrelated in the end.

Back to the features, despite their different meanings, population density and household size try to introduce the issue of the housing physical condition. In particular, the household size is different from density, which describes the number of people or houses per acre/sqm. Conversely, household size (partly similar to other variables, not considered here, as the number of households and the family size) highlights the crowding levels, focusing on how many households have more occupants than rooms. Potentially, despite many discussions around the strong positive link between density and COVID-19 cases, household size can become a strong predictor of COVID-19 risk (Hu et al., 2021).

In addition, commuting time within each county can partly describe the daily patterns of residents and potentially portray those practices that are more vulnerable to get COVID-19 infection.

3.3.2 Dependent Variables Selection

The Health Department’s COVID-19 GitHub repository is an online data source that contains data on Coronavirus Disease for several administrative US levels, from state, to county, cities and sometimes even neighborhoods (through zip code level). The prime origin of these data corresponds with the Centre for Disease Control and Prevention, known as “CDC”, active at state and local level through smaller agencies. As previously mentioned, data are subject to change, since they are updated daily and every week, public tables and data folders are updated online. In the context of this research, COVID-19 indicators are referring to the cumulative number of positive cases in relation to tested people in each US county (latterly, only US metropolitan counties have been extracted), the cumulative number of deaths in relation to residents in each US county, and the same data in relation to 100K people. In this case, data have been collected during the summer 2021, corresponding with the so-called **"third wave" related to the Delta variant of COVID-19**. They correspond with specific days, here referred to as "observation days".

Methodologically speaking, these data derive from the Centers for Disease Control and Prevention (CDC), through their state- and local-level public health agencies. County-level data are confirmed by referencing directly state and local agencies. Cases, deaths, and per capita adjustments indicate cumulative totals since January 22, 2020. Data will update Monday through Saturday as soon as they are checked and verified, usually before 8 pm ET. Nonetheless, sometimes updates may arrive later because of delays in processing data. Thus, all data from CDC are declared as "provisional".

In fact, because of this frequency in which data are continuously updated, sometimes they may not reflect the precise numbers reported by state and local government organizations or the news media. Totals may also fluctuate as agencies update their own information frequently.

In terms of data sources, the Coronavirus case classifications are collected and described in an updated COVID-19 position statement and case definition, issued by the Council of State and Territorial Epidemiologists. Though, there are some small differences sometimes in how jurisdictions apply these case classifications. Total cases base on aggregated counts of COVID-19 cases reported by state and territorial jurisdictions to the Centers for Disease Control and Prevention (CDC) since January 21, 2020, with the only exclusion of persons repatriated to the United States from Wuhan, China, and Japan. All displayed counts include confirmed COVID-19 cases and deaths as reported by U.S. states, U.S. territories, New York City (NYC), and the District of Columbia from the previous day. In accordance with the CSTE definition of COVID-19 cases and deaths, totals for many authorities include both confirmed and probable COVID-19 cases and deaths. COVID-19 case and death data that are not available to CDC are denoted by N/A. For aggregated state-level data, CDC calculates the number of new cases or deaths each day either by using the information provided by states and territorial jurisdictions or by calculating the difference in cumulative counts reported by the state from the day before. CDC also works closely with states and jurisdictions to integrate their historical data. The number of historical cases and deaths presented on CDC's website reflects the information provided by the states and jurisdictions.

Finally, it is important to clarify that CDC's overall COVID-19 case and death numbers are confirmed through a validation process with each jurisdiction. COVID-19 case and death numbers reported on other websites may differ from what is posted on the CDC COVID Data Tracker due to the timing of reporting and COVID Data Tracker updates, which may fluctuate by up to 24 hours. CDC COVID-19 counts from previous dates may be continually revised as more records are received and processed. Not all authorities report counts daily; some counts are reported in periodic collections and may increase COVID-19 case and death counts at different intervals and be seen as spikes. At the same time, the process used for finding and confirming COVID-19 cases and deaths presented by other sites may differ.

Within the context of this empirical step of the research, then the number of positive cases and deaths count have been collected, analysed and observed firstly at County scale-level and then in relation to population and socio-economic variables. These two, together represent the theoretical context of the urban-crisis analysis developed and support the wider understanding of the case study. Thus, in the next steps of the work, there will be a deeper explanation of this distinction and data will probably be updated over time, in order to keep tests, positive cases and deaths information as updated as possible and also to improve the methodological quality of the research.

3.3.3 Limits and strengths of the Dependent Variables Selection

When considering the daily cumulative cases index and the cumulative mortality index, it is clear that the real understanding of the virus among communities is actually influenced by several other factors. For instance, the prevention measures in place, the political rapidity in introducing them, and several other socio-economic and physical reasons can actively take part in the way these indicators are then read and interpreted. More specifically, the daily cumulative cases index, while describing the progressive growth of COVID-19 in different counties, can be considered as misleading because of the great difference of testing practice in each county. The same can be said for the cumulative mortality index (also in the version compared to 100K people), since this variable depends on the share of Coronavirus hospitalization. In fact, the reported fatalities occurred mainly in hospitals or similar health-care structures, where patients already got a positive test before dying. Therefore, unless some home-stay patients got tested before their conditions broke down, the reality is that most people who die out from hospital were not tracked, since the COVID-19 tests were carried out in a quite selective way. For these reasons, it is considered that the positivity rate, if ever calculated at the county level, would have appeared even less reliable than cases and deaths collections. A reasonable answer to that is that the opportunity to get tested for COVID-19 is too random and poor in comparison to the real need, especially at the beginning of the pandemic emergency. Moreover, because of the more recent request to get regularly tested from some job-places to workers, in order to return safely to work, the concentration of many workers having regular tests could provoke heavy biases. From this awareness, the positivity rate was not considered, so as to avoid a very imbalanced measurement among counties.

That clarified and considering the pros and cons for each feature, the current work considers both the daily cumulative cases index and the cumulative mortality index for use. They were regarded as separate descriptors of the Coronavirus spread and are then analyzed every time separately. Moreover, especially in terms of death, the normalization of the cumulative deaths per 100K people makes the result discussion more comparable and scalable among counties.

Finally, as already mentioned, the temporal observation for both the daily cumulative cases index and the cumulative mortality index includes the 2021 summer period, when the so-called Delta variant was circulating (III wave) especially in the US.

3.4 Unit of Analysis

When having to select the unit size to study the overmentioned relationship, it is actually important to have clear the question to deepen at that scale. According to the object of this study (deepening the relationship between population size/density and COVID-19 distribution), several scales can be considered in the analysis, from the county to the county and urban levels. Studies at the **county level** appear as the most appropriate to differentiate the effects of urban density from the one of external and internal connectivity. In fact, Hamidi et al. (2020) highlights that these three variables are not so much related when density is evaluated at the county level. Those studies that were completed at the county level did not include the same set of counties: some focused on metropolitan counties (Hamidi et al. 2020), while other studies considered all typologies of counties, whether rural or urban (Zhang &

Schwartz 2020; Jamshidi *et al*. 2020). Ideally only those counties with a sufficient number of cases/deaths should be included in the analysis, given the high uncertainty related to counties where many cases were reported (and many cases were ignored, on the contrary, or too late declared).

For instance, Wheaton and Thompson studied the relationship between population density and Coronavirus working at two different spatial scales: metropolitan statistical areas (MSA) and counties. They observed that at metropolitan level, density never covered a relevant weight, while when passing to counties, sometimes density covered a more relevant role in the COVID-19 distribution. These picks can be mainly associated, on one side, to high concentrations of commercial and recreational activities, while on the other, by a higher concentration of low-income families, both susceptible to the epidemic. Thus, the selection of a proper scale is very important to test the influence of population variables on COVID-19 behavior. At the beginning, early US studies on the pandemic issue usually chose the metropolitan statistical area as a unit of interest since data were easier to collect. Later then, the New York Times released a full COVID-19 dataset, in which the county level information were regularly updated. Therefore, researchers started to work also and mostly on the county-unit, being also relevant and well-structured in statistical terms. To date, the county represents the smallest unit with the most complete data collection publicly available. Luckily, this condition was particularly suitable for this thesis and its ambitions, because it allows to study the local population profile as a whole system where randomized social interactions took place. Moreover, differently from a city and a state, the county level represents a good compromise where several reflections can be developed, without losing the detail but without entering too much in more local dynamics typical of a city.

3.5 Temporal Impacts of Policy Intervention

Another important element to consider deals with the presence, at different impacts, of severe and several surges in different periods of the pandemic emergency. Starting from 2020, some counties showed earlier but less strong surges between March and April, while others entered in a severe infection-intensification around the summer. Yet when November 2020 arrived, many counties that did not experienced surges before, then started to face the most impactful wave ever, despite in the earlier summer months they seemed to be far from this winter emergency. These data-reports were actually published in late November, when the presidential election was over. The impact of this situation was visible also at Country level and in general and more comprehensive Regions (Figure 4 - 5).

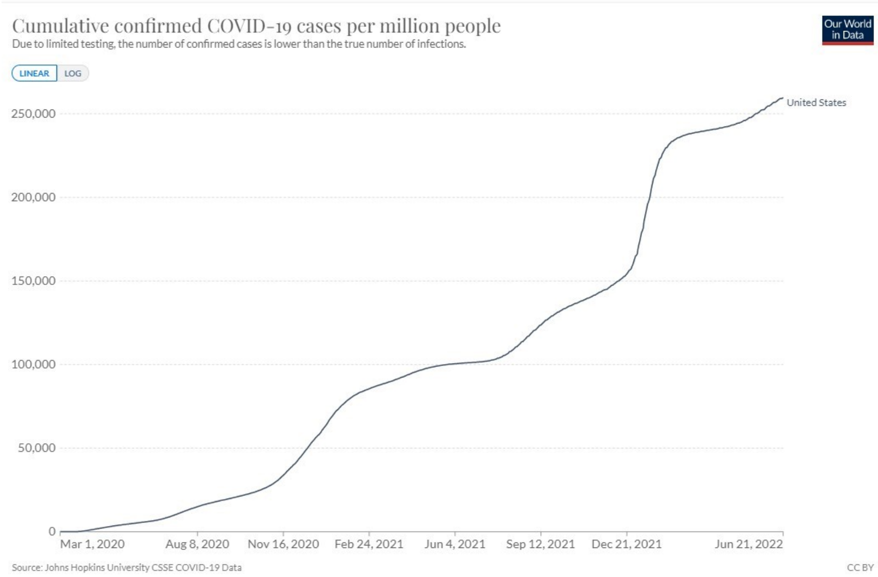

Figure 4 - Cumulative confirmed COVID-19 cases from March 2020 to June 2022
(Source: https://ourworldindata.org/covid-cases?country=~USA)

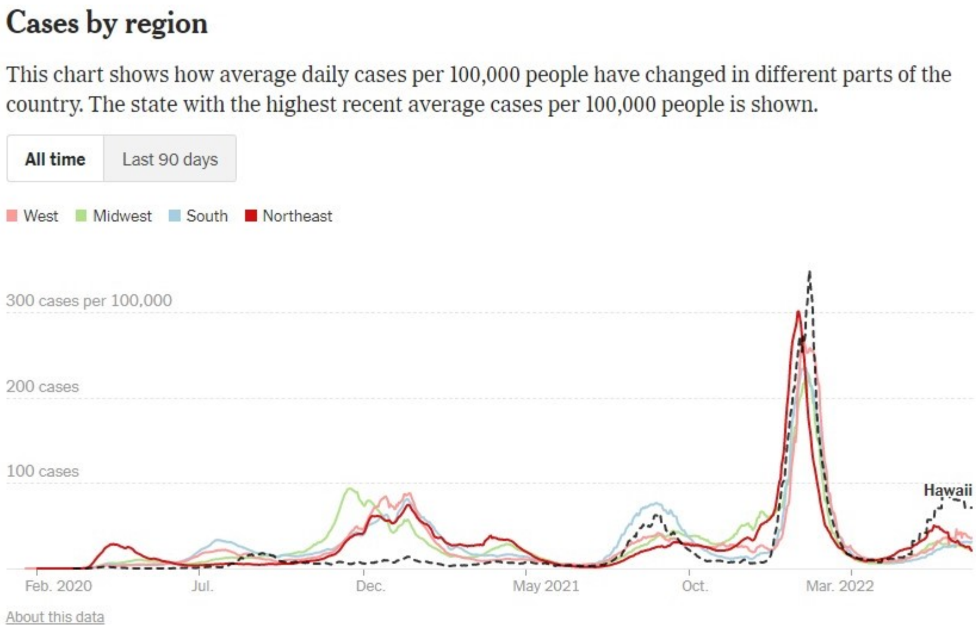

Figure 5 - Cases by region from February 2020 to June 2022
(Source: https://www.nytimes.com/interactive/2021/us/covid-cases.html)

Moving then to 2021, observations of cumulative cases reported the overmentioned summer peak, provoked by the spread of the Delta variant and just partially balanced by the vaccination process. In general, these results highlight the great impact the election had on COVID-19 distribution, following probably the major political belief of the local communities. According to the 2020 election results by county, acquired from *Politico* website (with about 25% county data missing), the political belief was very important also for influencing social behaviours against Coronavirus. A growing hypothesis is that places with denser Trump supporters were more likely to suppress and belittle the harshness of the pandemic, less disposed to protect themselves (and the others) with masks, medical alcohol, and social distancing, and therefore, and thus were more vulnerable to the infection. Even if it is not possible to collect county-by-county data about this trend, it is an interesting political element to consider, especially when concentrating the analysis on that 2020 specific period.

In addition to election preferences, despite some logical expectations may suggest that both cases and deaths should have followed a single-peak structure, in reality different policies, large events and distinct cultures can delay or anticipate the peak or repeat it several times. But at the same time, socio-political actions may have influenced the exponential COVID-19 growth, by introducing protective policies, strict quarantine, testing requirements, and so on.

These changes, however, are not enough to explain the role covered by population size and density in COVID-19 diffusion, as their impact and presence are supposed to be constant and quite static overtime. Therefore, an interesting way to capture and filter their role in this emergency, regardless of what the socio-political and cultural events introduced, is to focus on a specific period of the emergency where the curve reached one of its peaks. A bit differently from most literature, in this work, the peak under observation corresponds with the late 2021 summer wave, better known as "Delta variant" emergency[14]. At that time (late July – early August 2021), the major answer from policy was mainly related to the vaccination process, with around a 70% of American adults been vaccinated with at least one coronavirus vaccination unit and almost a 60% with full dose. However, the virus was not stopping to

[14] As Figure 4 and 5 show, another peak actually came after the Delta variant: the Omicron variant, that has been spreading in the late winter and spring of 2022. However, at that time, in parallel with the new Omicron variant, also the vaccination process was proceeding together with new policies (less restrictive) and the studying of new symptoms/reactions/and so on. This combination, if compared with the context of analysis applied for Delta variant (almost no vaccination yet, mostly the same symptoms as the first wave of 2020, and still some "original" social-distancing policies in place), would have risked confusing and "altering" the study context previously designed for the thesis, leading to more "polluted" and vague results. Therefore, despite the great wave of Omicron in early 2022, the thesis opted to keep the attention on the Delta experience in 2021.

circulate, especially in those states (and counties) with a low vaccination rate. For this reason, the 2021 summer became a good starting point, in which to collect COVID-19 information – definitely more dynamic – as well as population and socio-economic features – more "static" but representative of the context of interest.

CHAPTER 4

ANALYSIS OF THE CASE STUDY

> *It's going to disappear.*
> *One day, it's like a miracle, it will disappear.*
>
> US President (2017-2021) Donald Trump, 27 February 2020

The goal of this chapter is to provide, starting from the theoretical framework described in Chapter 2 and the crisis context of COVID-19 described in Chapter 3, an empirical assessment of the interactions between the dependent and independent attributes described in theory. This is achieved by a quali-quantitative approach that tests the efficacy, firstly, of the two population attributes (population density and size) in dealing with COVID-19 features and then, of the other socio-economic aspects in place when coronavirus disturbance occurred. Therefore, this chapter is central for the research and also represents the key passage from theories to practice. Because of its complexity, the first sections will present the analysis step-by-step, and then the other sections will move to the analysis understanding, discussion and deeper reflections.

In this way, the quantitative work will also address qualitative results of the first theoretical part, eventually answering to the research question, pointing out common lacks or new needs, limitations and opportunities to deal better with pandemic crisis, also in the future. How planners and local planning authorities will engage with the relationship between population features and the impacts of COVID-19 will be deepened in Chapter 5. This critical review might probably lead either to the understanding of some limits of the traditional built-environment, and either to the identification of new community, spatial and socio-economic needs, limits and qualities that were less considered in the theoretical phase, but that can drive to a new dimension in crisis-management and post-COVID-19 phase. Moreover, the identification of new pathways for planning may indicate potential new ways forward.

4.1 Overview on the case study: an introduction on the US Metropolitan Counties

Following the work-process mentioned above, to examine the relationship between positive COVID-19 cases and population (and socio-economic) characteristics, the research now moves to the introduction of the case study of the US Counties, with demographic focus on the metropolitan counties in the summer 2021. The area of investigation corresponds with the County administrative subdivision of states, that corresponds with a geographic region with precise boundaries and usually some levels of governmental authorities. US total counties are 3.243 (Figure 6).

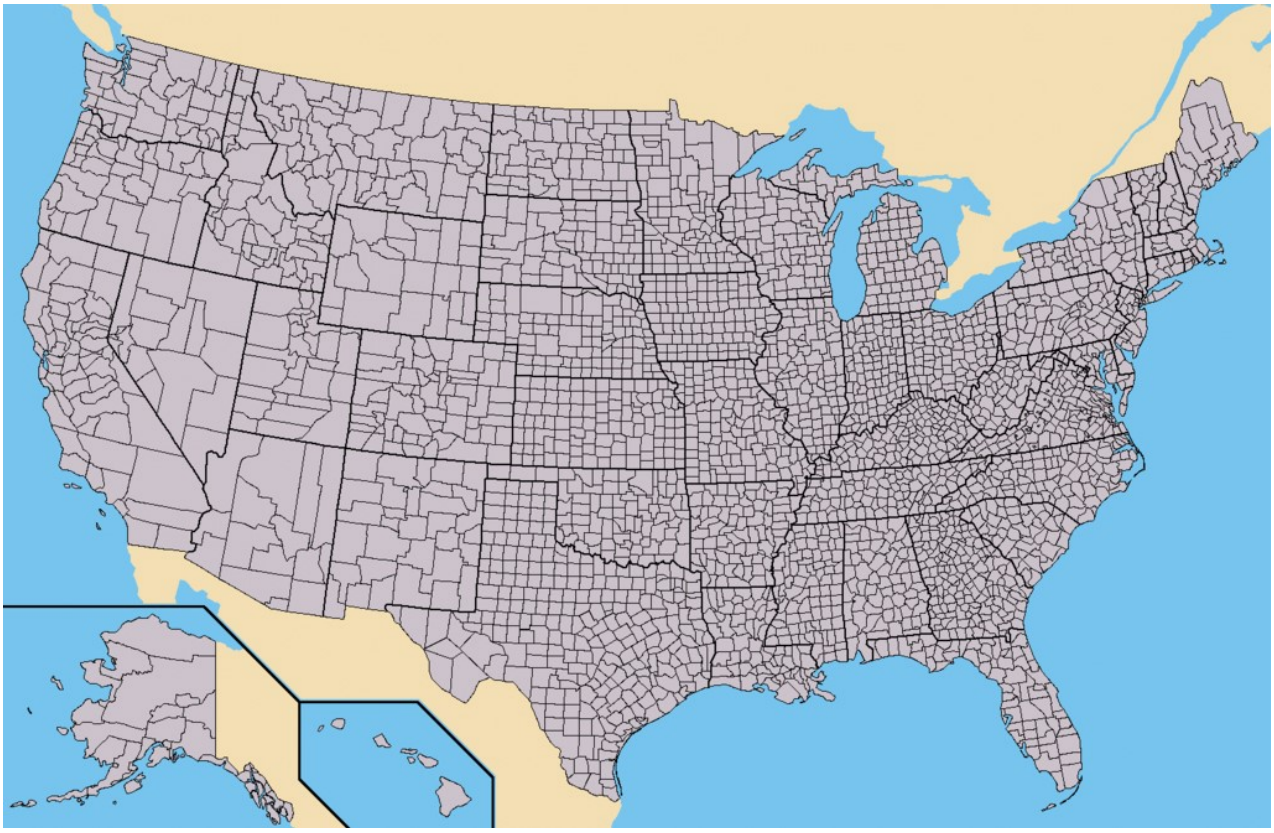

Figure 6 - Map of the USA showing borders of states and counties. Coloured version of adapted one by Wapcaplet from a public-domain map courtesy of the U.S. Census Bureau website first published in English language version of Wikipedia (Source: Wikipedia)

Most counties have, in turn, internal subdivisions responding with townships, municipalities and unincorporated areas. Others did not present any further subdivisions, or may serve as a stable city-county where a city corresponds with a county or more than one: this is the case of

New York City, which is uniquely portioned into its five Counties, namely, Bronx, Kings, New York, Queens, and Richmond (Figure 7). More commonly, they coincide respectively with the Borough of Bronx, Brooklyn, Manhattan, Queens and Staten Island.

Figure 7 – The five boroughs of New York: 1. Manhattan 2. Brooklyn 3. Queens 4. The Bronx 5. Staten Island (Source: Di Vector adopted by User: Nafsadh Original: Julius Schorzman, Public domain on: https://commons.wikimedia.org/w/index.php?curid=36401671 – Accessed on 30th September 2020)

The interest in metropolitan counties has its origins back in the spring 2020, when a lot of articles and TV services turned their attention to the American biggest cities, considered the "fertile ground" for the virus spread, mainly because of their density and population size. In fact, the higher numbers of COVID-19 victims are concentrated in several US cities as Florida, Texas, Chicago, Mississippi, Detroit and Memphis, without forgetting the remarkable case of NYC that since March 2020, has become the virus-epicenter in North America (Troung and Asare, 2020). Indeed, as of March 26, mostly 50% of confirmed cases in the US were found to be in NYC. In a very short period, this city saw the number of confirmed

COVID-19 cases grow at an astonishing rate. Logically, as stated by Hamidi et al. (2020), usually in large urbanized contexts there is a high number of social, economic and commuting relationships that are more vulnerable to the pandemic contacts. In addition to citizens, urban settings are also where business people and tourists usually move, thus increasing the risk of getting infected. Considering this concentration, the thesis passes to the distinction between rural and metropolitan counties, according to the already mentioned Office of Management and Budget (OMB)[15]. In their statements and codes, it is possible to read that counties are defined as Metropolitan, Micropolitan, or Neither. The simple application of their population targets reduced the number of counties to study from 3.243 to 923 units. These 923 counties can be considered Metropolitan and thus, at least according to some first (maybe superficial) interpretations, more at risk of infection.

Despite these confounding influences, the study aims to understand which factors, starting from the two population variables already mentioned (population size and density), are influencing more the distribution of COVID-19 cases and fatalities, as seen in the following maps (updated until the very end of the work, but available also for other periods in the Attachment – Section 1) (Figures 8 and 9).

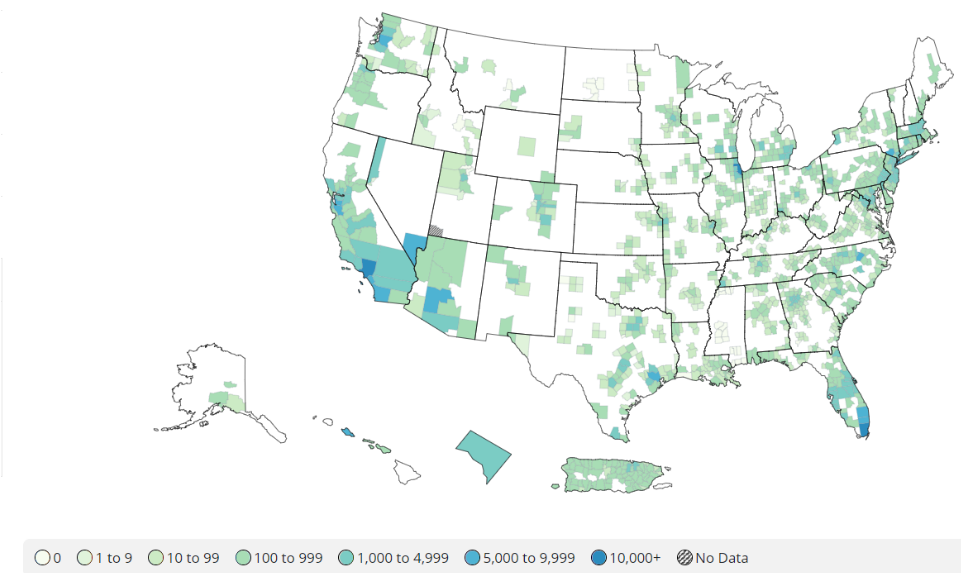

Figure 8 - Reported COVID-19 cases in US Metropolitan Counties –– Time Period: Sat May 28 2022 –– Fri Jun 03 2022 (Source: covid.cdc.gov – Accessed on 04th June 2022)

[15] Metro and non-metro status is defined by the Office of Management and Budget (OMB) as of February, 2013. Urban/rural classification type refers to the 2013 National Center for Health Statistics Urban-Rural Classification Scheme for Counties.

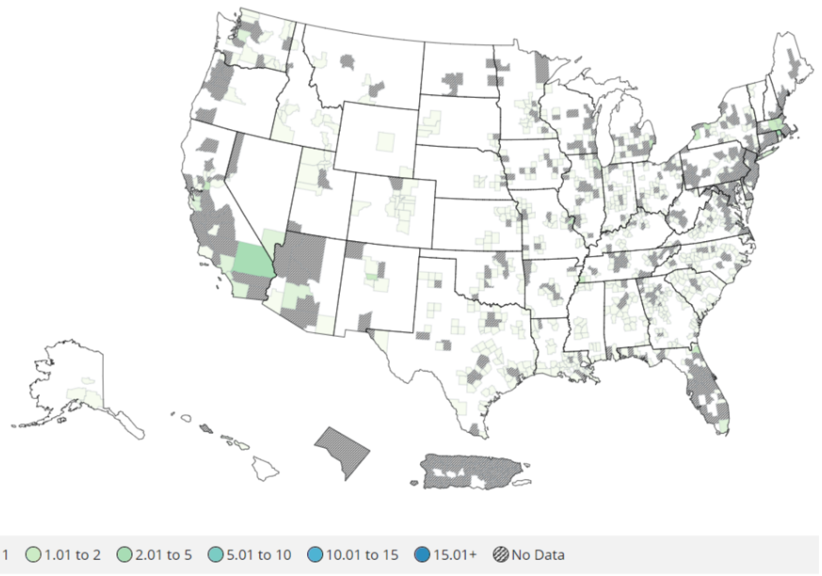

Figure 9 - Reported COVID-19 deaths per 100’000 population in US Metropolitan Counties -– Time Period: Sat May 28 2022 -– Fri Jun 03 2022 (Source: covid.cdc.gov – Accessed on 04th June 2022)

Among these metropolitan counties, it is worth mentioning the most affected by the virus in terms of cases (at least the first ten, thanks also to the Johns Hopkins database): Los Angeles – California, definitely the most affected county, with the greatest cumulative numbers (more than 1,5 millions of confirmed cases in November 2021); Maricopa County, Arizona; Miami-Dade County, Florida; Cook County, Illinois; Harris County, Texas; Dallas County, Texas; San Diego County, California; Riverside County, California; San Bernardino County, California; and Tarrant County, Texas. In terms of deaths, logically many counties are repeated: Los Angeles – California; Maricopa County, Arizona; Cook County, Illinois; Kings County, New York; Queens County, New York; Harris County, Texas; Bronx County, New York; Miami-Dade County, Florida; Clark County, Nevada; and San Bernardino County, California. An interesting observation points out that all these counties belong to a metropolitan context, where the variables observed are then inevitably linked to a more complex and dynamic demographic and socio-economic context. Another element to highlight is the physical proximity of some of these counties, whose borders are in common. This fact may suggest that the virus was carried through borders also thanks to regular commuters, travelling regularly from one county to another. This hypothesis, supported also by Hamidi et al. (2020)’s findings, needs further results directly based on the independent variables selected for the analysis. Another aspect, that will be mathematically addressed along the work, refers to the presence, among the most affected counties, of possible outliers. In statistical terms, an **outlier** is a data point that differs considerably from other observations and somehow "emerges" for this difference. An outlier may be related to variability in the measurement, to a different reference framework, or it may suggest experimental error, which can be sometimes excluded from the data set. An outlier can cause serious problems in statistical analyses, and for this reason it will be set aside in some quantitative passages later explained.

Considering the objectives of the present work, the conceptual background and the need to understand in detail the COVID-19 diffusion in the US metropolitan counties, it is necessary to specify that the quantitative analysis is based on the County code level, where the degree of precision is high and available data are quite local. The county is actually the smallest geographic unit for which complete and full access to virus data is available. Moreover, it is believed that working at this level is less risky, in terms of precision, to find aggregation bias than other analysis at the state or metropolitan level. The same can be said in terms of urban scale, where despite the deeper scale of analysis, the comparison between different cities is more difficult, since data are not homogeneously available among US biggest cities and the internal neighbourhoods conditions can widely differ from one city to another.

In relation to this research, the possibility to work with the county scale detail represents an opportunity to deepen the contextualized understanding of several variables, related to both the material and immaterial dimensions of cities. Once that quantitative analysis will provide data at the county level, then more qualitative and broader reflections will be conducted, in order to make more critical and interesting observations and comparisons between different socio-economic, cultural, functional and housing contexts of the case study.

Finally, through the adoption of the metropolitan county level as a case study, also other Asian and European contexts and big regions can replicate this approach, since they are all facing the same crisis experience and probably sharing also similar urban critical issues.

4.2 Empirical assessment: Covid-19 indicators and metropolitan county proxies

In this paragraph, the work deepens the empirical understanding of the crisis experience, working with two axes of indicators: the COVID-19 variables (here described through: the cumulative number of positive cases in each US metropolitan county and the cumulative number of deaths in relation to residents in each US metropolitan county) and the population and socio-economic proxies, that basically translate the theoretical attributes found in Chapter 2 into proxies at county level. These proxies, either more or less tangible, can provide an overview on the physical and non-physical as well as on the built and socio-economic environments to face the COVID-19 crisis at the county level. These data are particularly useful to clarify from the double point of view, of methodology and contents, the meaning of these attributes within this research.

In the literature background, despite Carpenter et al. (2005), it is not possible to build a single "correct mechanism" to develop proxies, many authors recognised the importance to identify and select indicators with proper criteria (Carpenter et al., 2005, Schipper and Langston, 2015). Firstly, to ensure reliability of the assessment methods applied, proxies should be supported by theories.
Secondly, proxies should be relevant to the phenomenon analysed. And despite sometimes the non-relevance is not immediately clear, the relevance or irrelevance of a specific variable should be tested in relation to the scale at which the crisis phenomenon is analysed. Third, the use of proxies should also allow comparisons between different systems experiencing the same phenomenon. Thus, proxies should be as objective as possible, but also transparent and repeatable in other independent contexts (as not lastly this work aims to do).

Last but not least, proxies can be really efficient when they are simple, immediate and affordable, but also relevant to the object of the study. Therefore, as demonstrated below, the choice of proxies has to consider possible barriers to data access and interpretation of results, preferring then those methods characterised by simplicity, without losing quality and detail of the provided information. This may also mean, according to Briguglio (2003), that sometimes some compromises between theoretical beliefs and practical evaluation may be necessary. Starting from these four criteria, the key passage to the empirical assessment will include the identification of several proxy indicators for the case study, considered as a reference and starting line of pandemic-determinants and response.

As a consequence, in this part of the work, quantitative urban form indicators, sometimes expressed through secondary data, are considered and put in relation through regression methods. This passage will allow to clarify the relationship in place between different aspects of metropolitan contexts and COVID-19 variables, starting also to identify first directions on which to develop further steps for planning and research.

That said, in the next sub-paragraphs and paragraphs, the selected proxies are processed through regression analysis, and related output graphs and tables. Further details on this quantitative passage and broader links are then discussed through charts and maps, to shed light on possible anomalies.

4.3 Data processing and preparation: the methodology applied

In this paragraph, the mathematical procedure will be presented, considering two approaches: the simple regression analysis and the multiple regression analysis. Although **the first is not influential in this research context**, since its products are too partial for a broader understanding of the research question, some theoretical contents and some outputs will be presented, in order to facilitate the understanding of the whole successively, through the multiple regression method.

More specifically, the simple linear regression method has some limitations since its common use to set up that a relationship exists between variables does not mean that correlation is equivalent to causation. In fact, even a line in a simple regression that seems to fit the information may not really represent a logical relationship. This is because the simple linear regression model permits to point out if a connection among variables exists by any means. But to see deeper the meaning of a relationship and if a variable causes another, then deeper statistical analysis is required.

For these reasons, the paragraph starts with the simple regression analysis sub-paragraph and then moves to the multilinear regression analysis approach, which is the real core of the mathematical procedure developed.

4.3.1 Simple regression analysis

Once collected and organized, the COVID-19 data and the several County proxies were imported in Excel, in order to start observing and relating them through linear regression analysis. Concerning the information about the virus, data were split into two separate worksheets: one containing COVID-19 absolute cases and deaths numbers by County, the other containing COVID-19 cumulative number of cases (on tested people) and deaths by County. In this way then, each independent variable has been reported in each worksheet, so as to be applied both to the COVID-19 cumulative cases and deaths values.

Proceeding then in parallel to both worksheets, the work passes to the regression analysis that, in statistical modelling, consists of a set of processes for estimating the relationship between a so-called "dependent variable" and one or more "independent variables". While the first one refers to a variable that somehow "depends" on the dynamics of another one (or more), the second one is a feature of the observed system that assumes its own values independently.

In a first step of the study, the form of linear regression analysis applied is the simple regression, used to study the relationship between two variables. This method basically allows to estimate the conditional expectation of the dependent variable (in this case, the COVID-19 data) when the independent variable (in this case, one among the county proxies) assumes a series of values. It is particularly useful to both understand the current tracks of the virus diffusion (dependent variable) in relation to the several county proxies (independent variables), to suppose causal relationships between the independent and dependent variables, and to somehow predict and suggest future developments of the COVID-19 diffusion in relation to several physical and non-physical variables of the city (population size, density, housing size, and so on). To do so however, the work must carefully explain why two variables have a causal relationship, how to interpret, and why the observed relationships can be useful to understand also future pathways of the relationship.

In practice, the process first selects a model to estimate and then uses the linear regression method to estimate the single relationship of that model. The components involved in the regression model are always:

- The "unknown parameter", usually called scalar or vector β,
- The "independent variable(s)", usually denoted as the vector X_i,
- The "dependent variable(s)", usually denoted as the vector Y_i,
- The "error terms" or "disturbance" in the relationship (e_i), that are not directly observable in data and are often symbolised through the scalar e_i. This variable represents factors other than x affecting y. A simple regression analysis actually treats all factors affecting y other than x as being unobserved. Thus, it is allowed to think of the "error terms" as standing for "unobserved."

Together, they propose Y_i as a function of X_i and β, with e_i representing an extra error term that may explain the track of Y_i and its random statistical noise:

$$Y_i = f(X_i, \beta) + e_i$$

Equation 1 – Regression model equation (Source: Harvard Business Review, 2015 – Accessed: 10th October 2020)

The equation assumes to represent the population of interest, through a simple linear regression model. For these reasons then, in Ecometrics (2012) it is also-called the two-variable linear regression model or bivariate linear regression model because it associates the two variables x and y.

Using these definitions and this function, the work presents now some of the most interesting outputs of the regression models and related observations. The rest of the simple linear regressions are collected in the final attachments (Section 2). For several reasons (further implemented), the simple regression model shows some limitations as a general tool for empirical analysis, especially when the context of study shows a certain complexity as the current one. However, for a small selection of variables already addressed in COVID-19 literature, it is sometimes proper as an empirical tool to analyse the correlation between two variables. Moreover, learning how to interpret the simple regression model is a useful practice for understanding multiple regression, which will be deepened in next paragraph (5.2).

According to the research topic and the literature presented, the following relationships may cover a crucial role in the understanding of COVID-19 behaviour at US metropolitan scale.

A. COVID-19 cases and deaths in relation to population

Quite easily predictable, the first relationship of interest concerns the link between COVID-19 variables and the population size. Indeed, this feature has been considered particularly relevant to determine the vulnerability of people living in a place to the virus or, said in other terms, the exposure degree that potentially puts them in contact with the disease.

Therefore, in this first and quite predictable regression model, COVID-19 deaths and cases (recorded in mid-August 2021) are the dependent variables put in relation to the population size in each US metropolitan county (tot. 923) (Chart 1 and 2), following a straight line to establish the relationship between them.

Logically, those counties presenting higher population sizes are also those more infected by the virus: indeed, high presence of people living, moving and interacting increases the probability to get infected. Moreover, from this graph and from the R^2 value it is interesting to notice that population size presents a constant positive correlation with positivity and fatality. Moreover, something that can influence these records is actually the number of people getting tested and then resulting positive. In this sense, charts tend to demonstrate that despite a general trend in that positive direction, it would be an oversimplification to put population size and COVID-19 transmission as a logical contagion condition. In fact, it would be illogical to assume that this observation is totally transparent since it is impossible that these data are completely exhaustive in what they describe. As previously pointed out, who turns positive is actually someone that officially got the infection through a test. Thus, the undeclared data of those without the possibility of carrying out a test should be at least kept in mind.

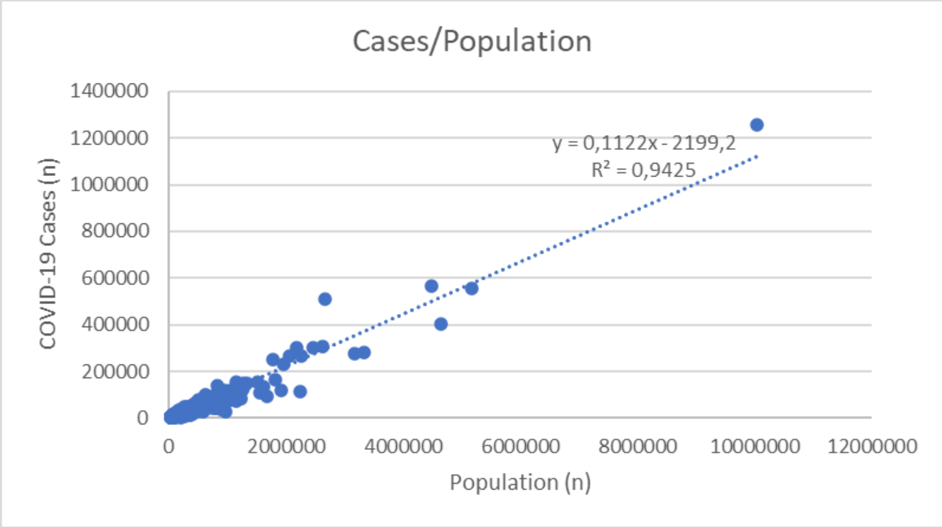

Chart 1 - *Cumulative number of COVID-19 cases in relation to population size by US metropolitan county (Source: Personal elaboration of CDC.gov and GitHub databases).*

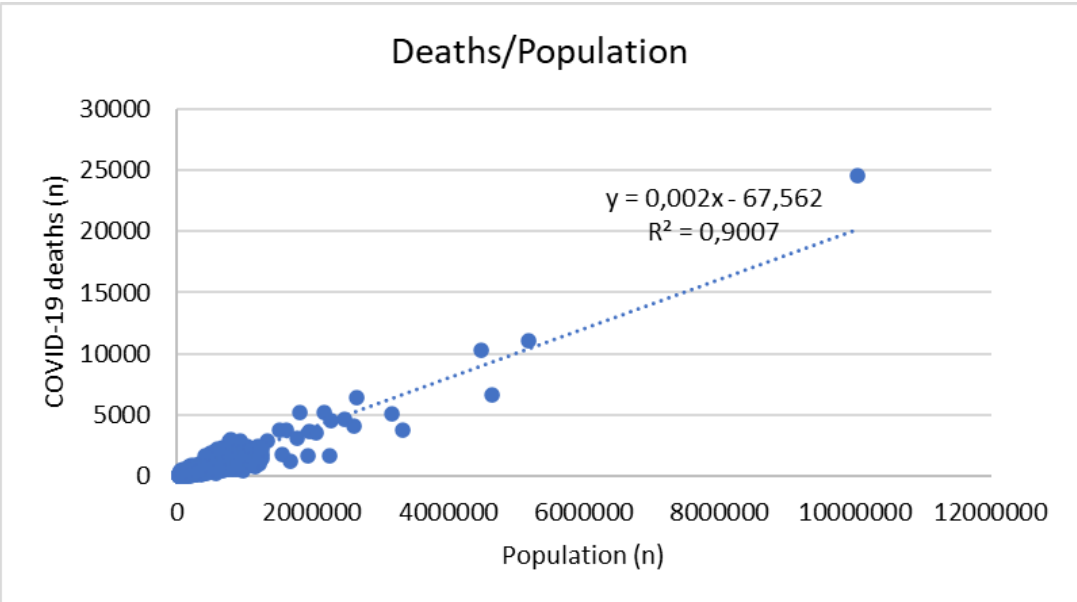

Chart 2 – Cumulative number of COVID-19 deaths in relation to population size by US metropolitan county (Source: Personal elaboration of CDC.gov and GitHub databases).

Despite the strong relationship reported, it is interesting to also understand the combination with other physical factors involved in this dynamic.

However, as already said, this relationship is very simple, obvious and needs further elements to prove stronger connections also with the other proxies and, consequently, with the possible outputs of the work.

B. COVID-19 cases and deaths in relation to density

As previously clarified, to conduct a simple linear regression, it is fundamental to make certain assumptions about the data. In this sense, following Hamidi et al. (2020), the COVID-19 pandemic represents a perfect case to study the relationship between density and the diffusion of highly infectious diseases. Once again, the simple linear regression model becomes a simple and direct way to study the correlation between density levels and the rise of COVID-19 in US metropolitan counties. Indeed, the early literature and interest on the topic is trying to understand the role that population density plays in the spread of the pandemic. However, as already pointed out, correlation is not the same as causation: thus, a strong (or light) connection between two variables does not mean one causes the other to occur.

Back to facts, at the beginning of the pandemic crisis, New York Governor Andrew Cuomo attributed the severity of COVID-19 in his city to urban density and tweeted: "There is a density level in NYC that is destructive" (Holland, 2020). However, according to some studies, despite infectious disease rises faster where people are more densely clustered, that does not necessarily make urban centers unsafe places (Bliss and Capps, 2020). In reality, density is likely just one among many key factors that determine the vulnerability of places to the virus. Several studies are concentrating on this topic and they will be cited and better discussed in Chapter 5. Here, a focus on the role played by density in the US metropolitan counties in limiting or favouring the virus-spread (Chart 3 and 4):

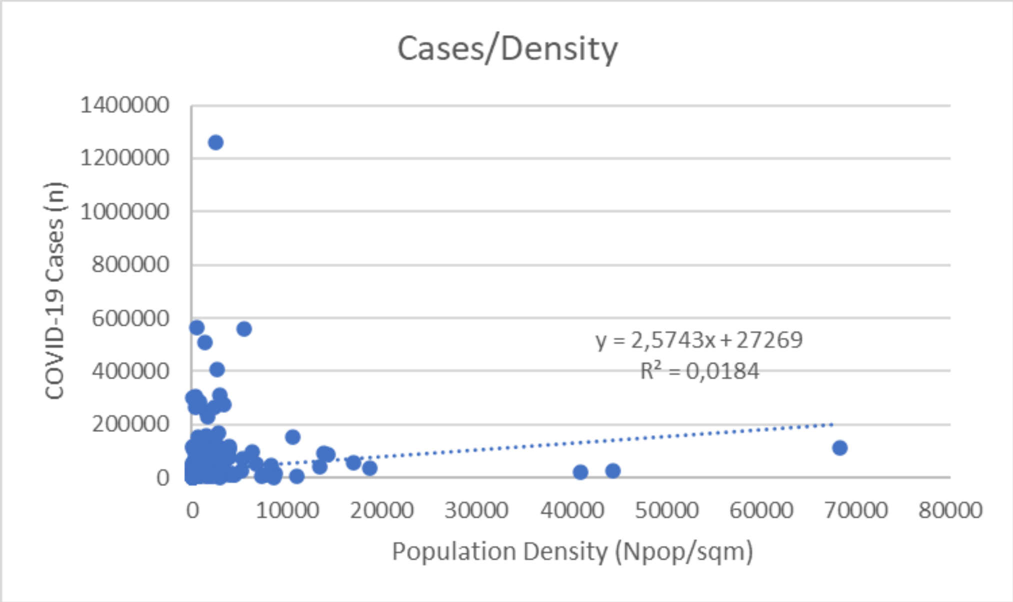

Chart 3 – Cumulative number of COVID-19 cases in relation to population density by US metropolitan county (Source: Personal elaboration of CDC.gov and GitHub databases).

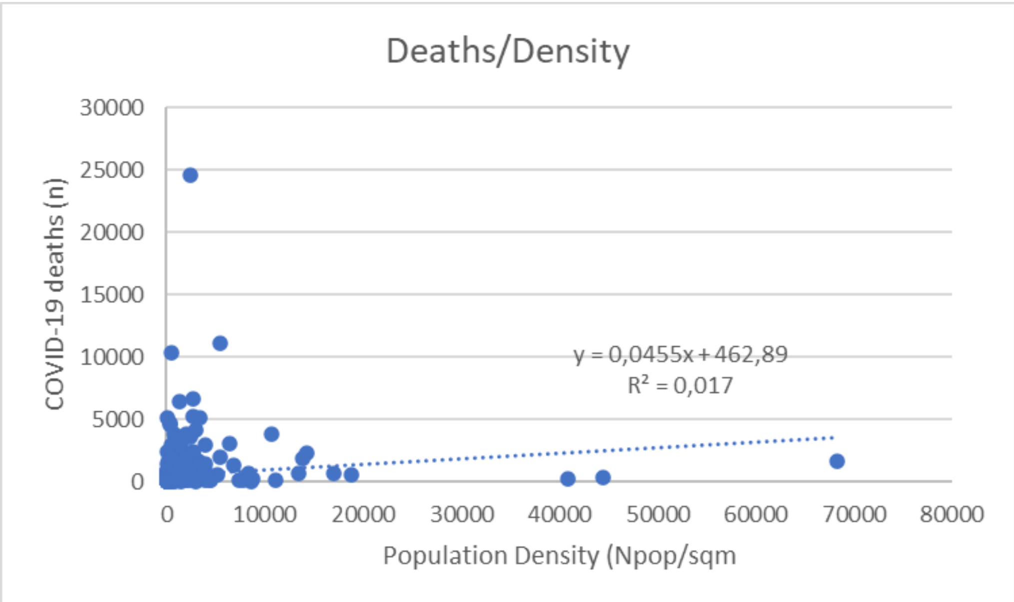

Chart 4 – Cumulative number of COVID-19 deaths in relation to population density by US metropolitan county (Source: Personal elaboration of CDC.gov and GitHub databases).

What appears quite clearly from these charts is that, at least for the simple regression analysis, the relationship between high levels of density and values of COVID-19 cases and deaths is very low. This may mean that in terms of causation, it is no density itself that makes the counties susceptible.

Despite the New York City region being a major hotspot for COVID-19, there are 70 counties in the US that have higher virus case rates than Manhattan, many of which are located in rural areas and present extremely low levels of population density. Back to the model of New York, the Bronx and Staten Island (both in the NY region) have similarly high numbers of infected, yet are very different in terms of population density. The Bronx has the highest rate of COVID-19 cases among the five boroughs, despite being half as dense as Manhattan and slightly less dense than Brooklyn. Remaining on this zoom, Staten Island is New York City's least dense borough, with only 8,300 residents per square mile (one third the population density of Manhattan), yet present the second highest virus case rate in the city. Although the Bronx is 4x as dense as Staten Island, its presence of positives is only 12% higher. Moreover, those areas in NYC with the highest rates of COVID-19 cases are much less dense than many other neighbourhoods (Figure 10 a and b as of May 18th 2021).

A. B.

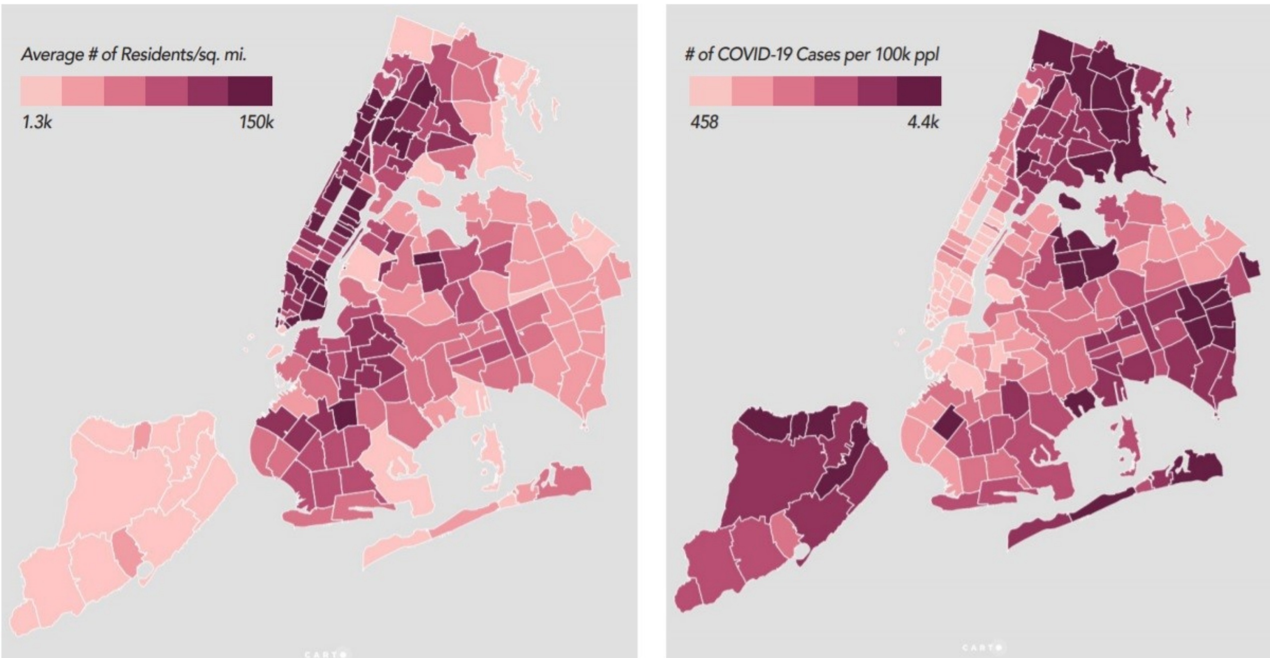

Figure 10 – Figures a and b demonstrate that, rather than seeing higher rates of COVID-19 in denser neighbourhoods and lower rates of the virus in less dense neighbourhoods, lower density areas have some of the highest case rates in the city (Source: https://www1.nyc.gov/site/doh/covid/covid-19-data.page#maps).

According to some studies, the density transmitting Coronavirus is that of multifamily conditions, multi-generational households or occupations in close physical contact to the public (Florida, 2020). These observations suggest that it cannot be said that the connection between density and COVID-19 variables exists by any means: further studies should be developed, deepening other indicators as possible "key-players" in favouring the spread of the virus within the city. Next paragraph tries to address one of the other possible "key-player", analysing the correlation between COVID-19 variables and a more specific kind of density, frequently addressed by recent literature on COVID-19 distribution in urban environments.

C. COVID-19 cases and deaths in relation to the average household size

As previously emerged from observations and literature, COVID-19 diffusion is closely related to household size in a negative way. This indicator refers to the average number or household members who usually live (as residents) in a household. Considering that population consists of "households" and the inter-household and intrahousehold dynamics of an epidemic differ profoundly (Federgruen and Naha, 2020), the contact rate between a pair of individuals living in the same house tends to be much greater than that between two individuals from different nucleus. Thus, starting from the seminal papers by Bartoszynski (1972) and Becker (1977), this observation has been the crucial point of many epidemiological models. According to recent literature (Harris, 2020; Hu et al., 2020; Maroko et al., 2020; Wheaton, 2020; Wong and Li, 2020), household size represents a strong predictor of the COVID-19 risks, especially if compared to urban density impact, which remains quite limited in several urban contexts. Consistent studies demonstrate the relationship between house crowding and COVID-19 cases in big cities, as New York City (Medical press, 2020; Maroko et al., 2020) and Chicago (Maroko et al., 2020; PropPublic Illinois, 2020) and other metropolitan areas, therefore concluding that the level of household-crowding can be a strong predictor of the COVID-19 diffusion.

Once again, the regression model offers an interesting perspective to study the effects of the average household size on the rise of COVID-19 in metropolitan counties. However, due to some scale limitations, the observation can be supported by a more local scale, such as the New York City scale (previously analysed by the author), where data for neighbourhoods (Charts 5 and 6) have been collected, during an observational time from June 2020 to March 2021.

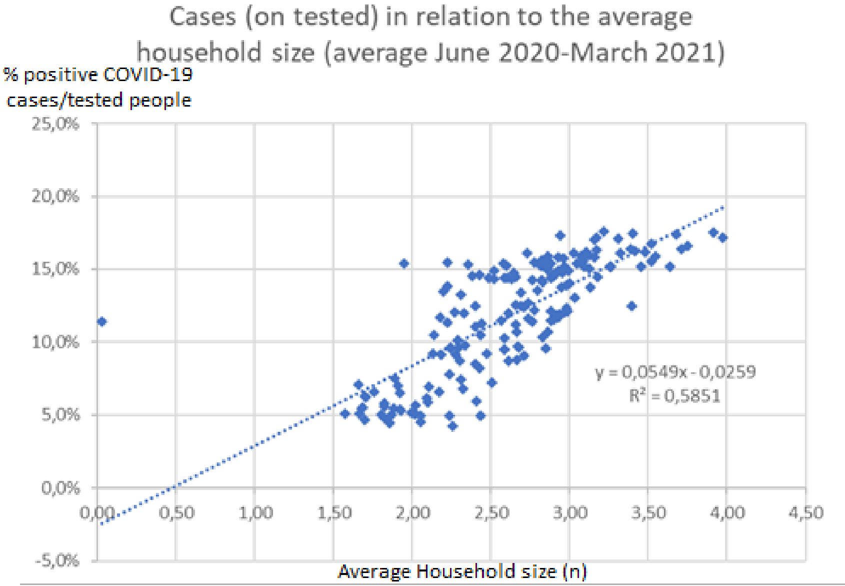

Chart 5 - Percentage of COVID-19 cases on tested people (the average value between June 2020 and March 2021) in relation to the average household size by NY ZIP Code (Source: Personal elaboration of Health Department and ZIP Atlas databases).

This zoom has the potential to make useful distinction between levels of density and levels of household-crowding and, when passing to the interpretation side of the work, can lead to new evidence and connections between different spatial proxies and the Coronavirus diffusion.

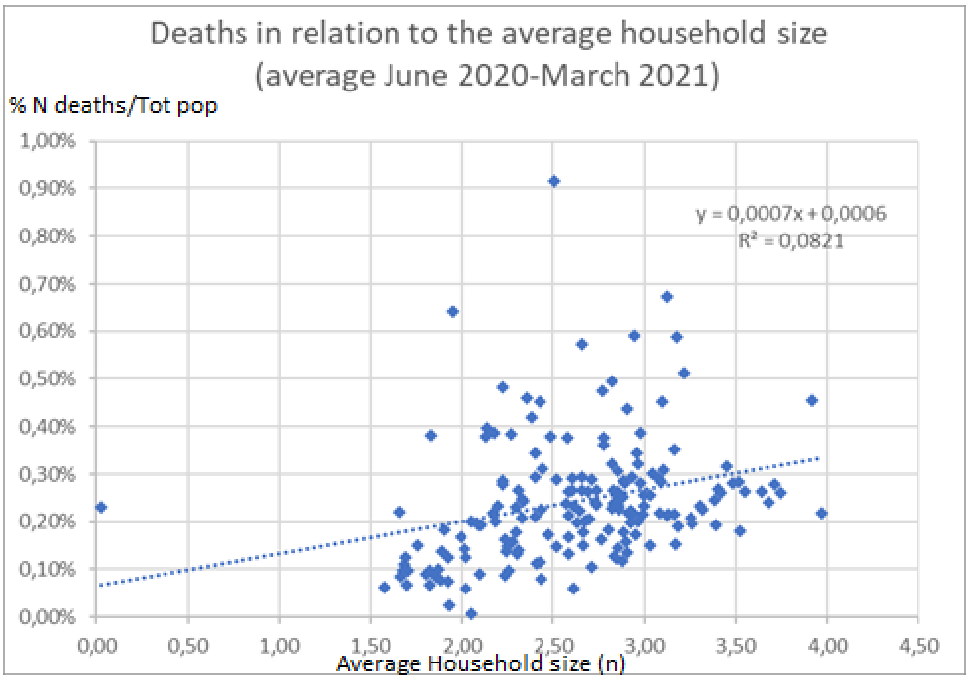

Chart 6 – Percentage of COVID-19 deaths (the average value between June 2020 and March 2021) in relation to the average household size by NY ZIP Code (Source: Personal elaboration of Health Department and ZIP Atlas databases).

According to data-observation, the average of household size in New York neighbourhoods is correlated with COVID-19 cases and deaths, more explicitly with negative impact that favours the contagion and virus circulation. In fact, from Chart 5, it is evident that the average household size emerges as an important explanatory variable with a R^2 = 0,5851. The worst hot spots are represented by communities in the South Bronx, north and southeast Queens, and much of Staten Island. Indeed, this kind of "internal residential density" makes distancing and isolation more difficult. Similar to Chicago, also in NY households appear to be larger, instead of an overall population density, that may be more strongly related with local hot spots of contagion (Maroko et al., 2020).

Coming back to the US metropolitan county level, observations on cumulative data for the summer 2021, are quite in line with more detailed observations from NYC (Chart 7 – Chart 8).

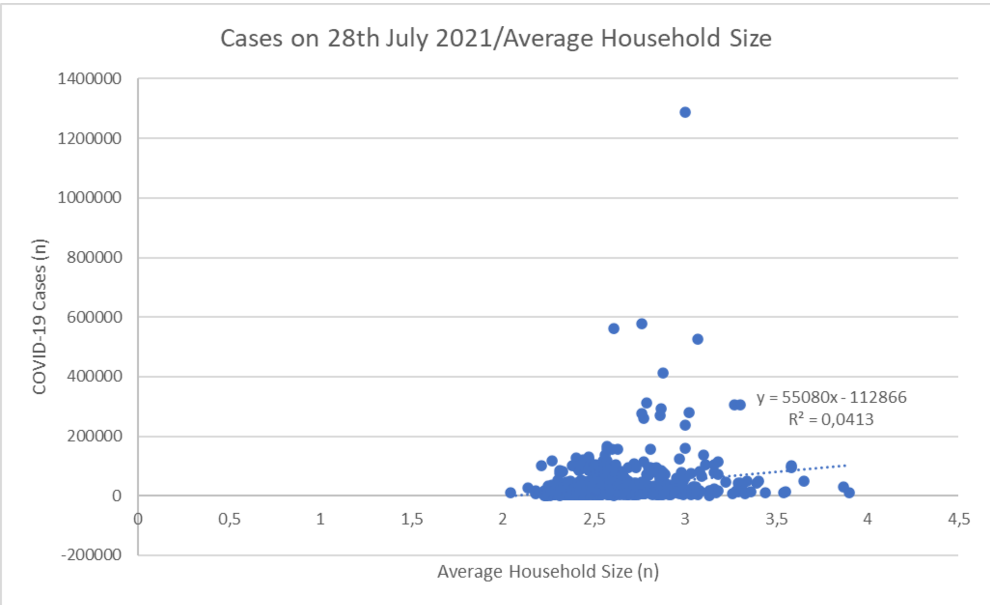

Chart 7 – Cumulative number of COVID-19 cases (on 28th of July 2021) in relation to the average household size by US metropolitan counties (Source: Personal elaboration of CDC.gov and GitHub databases).

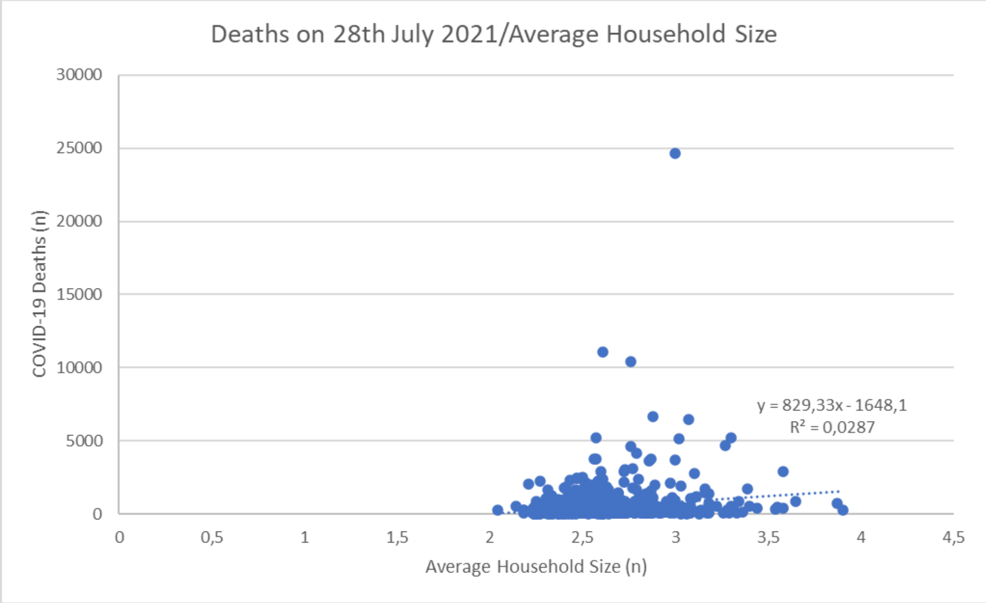

Chart 8 – Cumulative number of COVID-19 deaths (on 28th of July 2021) in relation to the average household size by US metropolitan counties (Source: Personal elaboration of CDC.gov and GitHub databases).

A possible limit of this indicator, in addition to all the limitations related to the simple linear regression approach, is that it tries to describe what may happen within the domestic environment in terms of infection spread, despite the scale is larger and the county level is far from the neighbourhood and building ones. Moreover, in line also with other "static" indicators, the average household size may not realistically represent the most updated condition of families in terms of present members, especially at the time of pandemic outbreak, when in several urbanized contexts, people tend to move in their second homes in the countryside. Thus, when reading this indicator, there is reason to reflect on possible externalities that may alter the average household size behaviours and outcomes.

D. COVID-19 cases and deaths in relation to commute time

Following again the literature framework, the interest for this proxy has its roots in less and more recent publications, where several studies have been developed in last years about the connection between mobility patterns and infectious disease dynamics. For instance, Dalziel et al. (2013) states that "Systematic variation in mobility patterns is sufficient to cause significant differences among cities in infectious disease dynamics" (p:1). Indeed, the commuting habits of people influences the frequency and duration of contact between each possible worker in a city. And despite that, in reality, cities are connected also by inter-city commuting patterns, these are relatively weak if compared with intra-city commuting habits (Dalziel et al., 2013). Thus, in this specific case study, it is interesting to understand what is the relationship between time spent to commute and COVID-19 diffusion, even though simple linear regression may not ensure a full representation of circumstances. Next charts (Chart 9 and 10) demonstrate how they are related, using rate values for both COVID-19 indicators and for the commute-proxy, here meant as the commuting flows from the Residence County to the Workplace County (2011-2015). Once again, these charts demonstrate the existence of a correlation between the two variables, leaving to more qualitative interpretations (and/or further deepen quantitative analysis) any comments about the existence of a causation-condition:

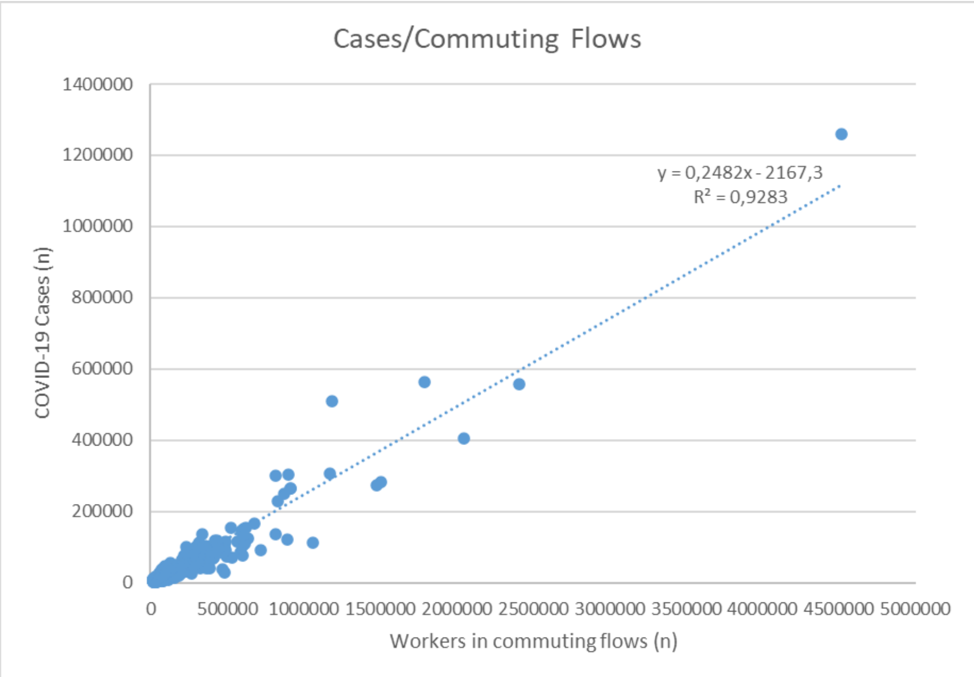

Chart 9 – Cumulative number of COVID-19 cases in relation to commuting flows by US metropolitan county (Source: Personal elaboration of CDC.gov and GitHub databases).

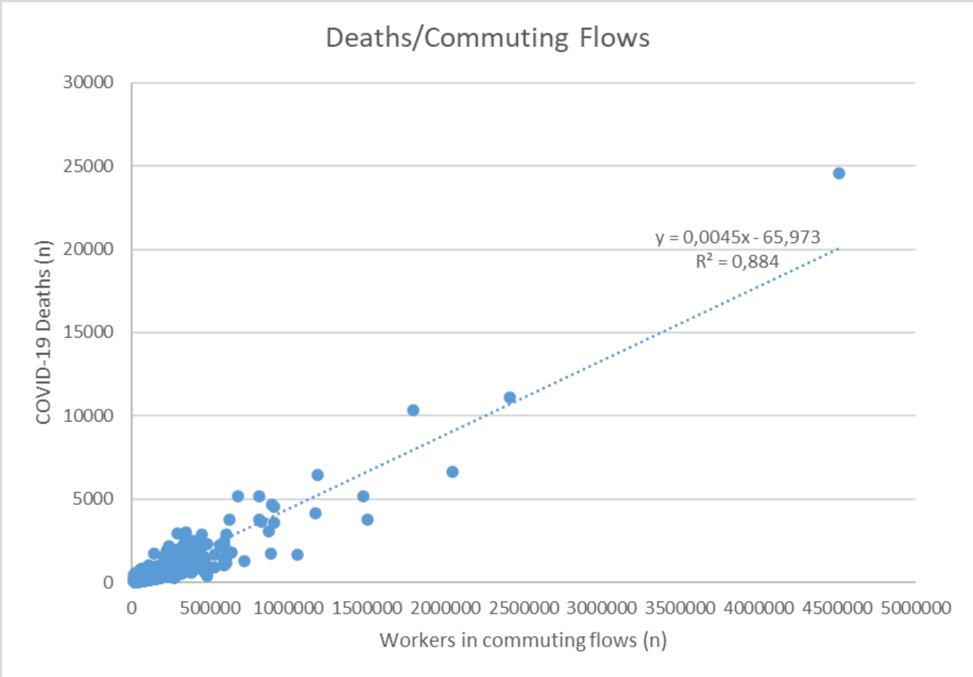

Chart 10 – Cumulative number of COVID-19 deaths in relation to commuting flows by US metropolitan county (Source: Personal elaboration of CDC.gov and GitHub databases).

Quite clearly, from these charts it seems that counties with higher commuting patterns demonstrate a higher number of both COVID-19 cases and, probably latterly, of deaths. These values may have a great potential in showing new evidences of causality about Coronavirus transmission in the US mobility-patterns and also in successfully addressing critical commuting plans that should be reorganized. This concern may in particular address public transport that, as demonstrated below, has some influences too on the virus diffusion. Another interesting perspective may derive from the observations of the transportation workers category on the share of positive cases: in fact, Almagro and Hutchinson (2020) pointed out that non-essential professionals, other health workers and transportation occupations are all well associated with a higher percentage of positive tests.

In this perspective, as pointed out by the National Association of Realtors, it would be interesting to deepen the topic of work-from-home, since, during the pandemic, sixty-two percent of Americans worked from home and three in five U.S. workers who worked from home at that time, then preferred to continue to do so. In fact, working from home can be considered one of the most effective strategies to slow the disease spread, minimizing human-to-human contact through proper measures of social distancing. Between the several ways discussed, work-from-home policies seem to be potentially effective and helpful, as they reduce workplace interaction as well as time spent to travel from home to work daily (Hamidi et al., 2020; Chu et al., 2017). However, as stated by Harris (2020) when observing London trends, not all jobs are suited to home working: indeed, among several occupations (see Almagro and Hutchinson, 2020 to have further information about occupation-categories in New York City), only a small part of workers has the ability to better isolate through home-working or even to temporary move to less populated zones. Therefore, in order to develop further reflections to the work-from-home condition in the US metropolitan counties, it would be necessary to collect updated data, capable of integrating the new trends adopted after the pandemic experience. Before the pandemic, according to the National Associations of Realtors, the top work from home counties were those in Table 3, usually belonging to metropolitan contexts with high internet broadband access, presence of three or more providers, low home prices, high presence of homeowners, high percentage of people working in high-service sectors, population growth trends, and so on. In these contexts, the pandemic impact measured through the cumulative number of cases was quite limited during the summer 2021. This evidence can partly be linked also to the trend, already in place, of working from home, as these places are usually metropolitan areas where the population is served by high-quality broadband internet service providers (ISPs) and where homes are quite affordable.

Table 3 - Top 1% Work from Home Counties as of 2019 (Source: https://www.nar.realtor/research-and-statistics/research-reports/work-from-home-counties)

	Work from Home Score	Percent of workers who worked at home	Percent of population with 3 or more broadband ISP (s)
Forsyth County, Georgia	1.9	11.3%	99.0%
Douglas County, Colorado	1.8	11.7%	98.3%
Los Alamos County, New Mexico	1.7	2.55%	96.9%
Harding County, South Dakota	1.7	27.0%	100%
Collin County, Texas	1.6	8.6%	99.4%
Loudon County, Virginia	1.6	7.5%	100%
Hamilton County, Indiana	1.6	8.3%	99.9%
Williamson County, Tennessee	1.5	9.7%	94.1%
Delaware County, Ohio	1.5	8.1%	99.4%
Broomfield County, Colorado	1.5	9.9%	93.6%

Dallas County, Iowa	1.5	4.6%	97.2%
Wake County, North Carolina	1.4	8.9%	99.8%
Williamson County, Texas	1.4	7.9%	94.7%
Denton County, Texas	1.4	7.2%	99.9%
Cherokee County, Georgia	1.4	9.1%	97.4%
Perkins County, South Dakota	1.3	26.4%	96.7%
Rockwall County, Texas	1.3	6.5%	97.9%
St. Johns County, Florida	1.3	8.6%	100%
Johnson County, Kansas	1.3	6.2%	100%
Cobb County, Georgia	1.3	8.1%	98.0%
Falls Church city, Virginia	1.2	7.8%	98.6%
Mecklenburg County, North Carolina	1.2	7.2%	100%
Fort bend County, Texas	1.2	5.3%	92.6%
Carver County, Minnesota	1.2	6.8%	98.0%
Arlington County, Virginia	1.1	6.6%	98.1%
Lincoln County, South Dakota	1.1	4.6%	94.8%
Travis County, Texas	1.1	8.8%	99.9%
Comal County, Texas	1.1	7.3%	99.2%
Utah County, Utash	1.1	7.0%	92.5%
Ziebach County, South Dakota	1.1	27.1%	100%
Seminole County, Florida	1.1	7.3%	100%
Boulder County, Colorado	1.1	11.5%	93.3%
Fairfax County, Virginia	1.1	6.4%	98.4%
Grant County, North Dakota	1.1	23.4%	96.1%
Warren County, Ohio	1.1	6.2%	97.9%
Howard County, Maryland	1.1	5.7%	96.4%
Fulton County, Georgia	1.1	8.2%	98.4%

Despite data at the County level are not available for this analysis, it is interesting to point out that moving to the city level, in big cities like New York, the connection of this habit on COVID-19 is quite strong, since in those neighbourhoods where people where more likely to work from home already before the pandemic, then the virus impact was more limited (Charts 11 and 12).

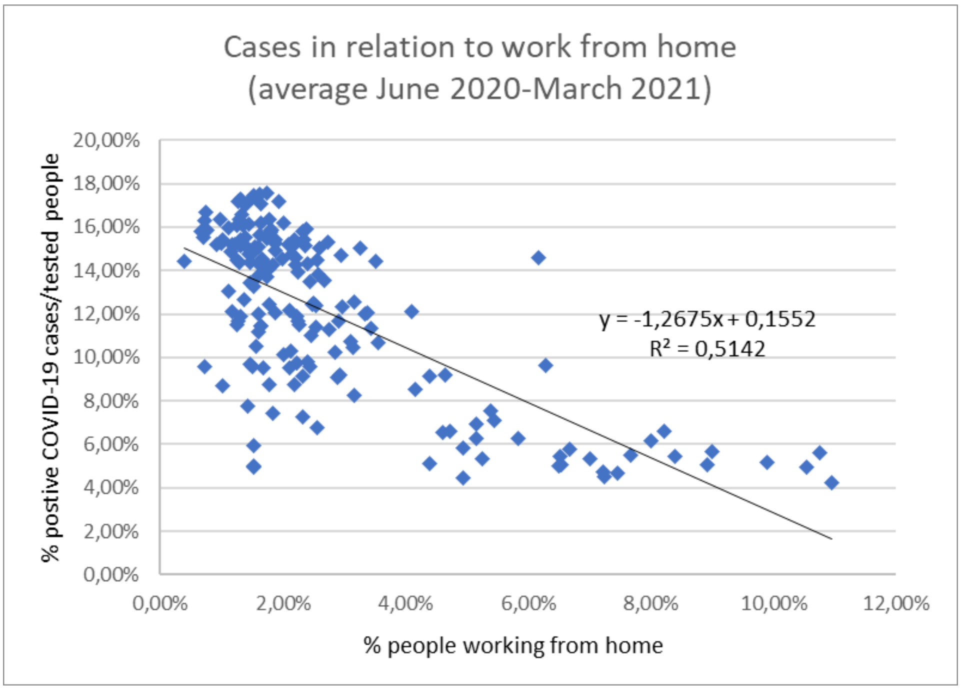

Chart 11 – Rate of COVID-19 cases in relation to the percentage of people working from home by NY ZIP Code (Source: Personal elaboration of Health Department and ZIP Atlas databases).

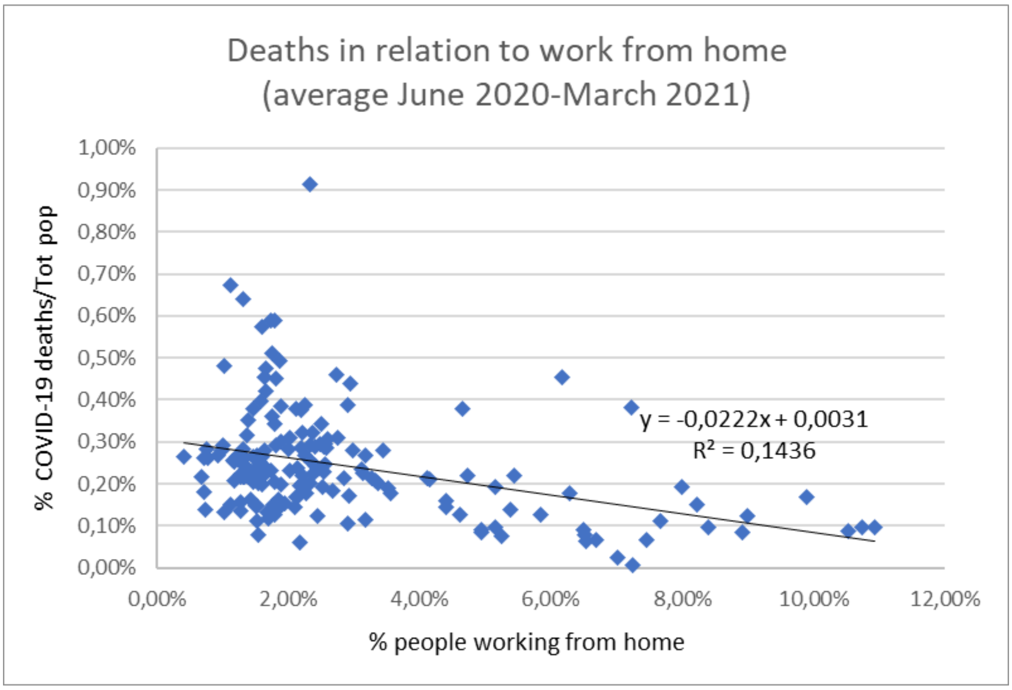

Chart 12 – Rate of COVID-19 deaths in relation to the percentage of people working from home by NY ZIP Code (Source: Personal elaboration of Health Department and ZIP Atlas databases).

Despite data about US metropolitan counties may be different and would be more useful, the presence of a relation between the two variables at city level is quite surprisingly: indeed, from these representations there is strong evidence to state that in NYC, in addition to an evident correlation, also a strong inverse relation exists between rate of COVID-19 cases/deaths and percentage of people working from home. In a nutshell, those neighbourhoods where people are less used to work from home are also those with more Coronavirus positives and victims. This outcome has several connections also with the issue of occupation and incomes, since it seems that lower income citizens are more likely to travel in the city and cross public spaces because of their employment obligations (Honey-Roses et al., 2020). In the United States, Valentino-DeVries et al. (2020) underline that geospatial data revealed that lower income workers continued to travel around also in the midst of the pandemic crisis, while higher income workers could more likely work from home. Thus, skilled workers can more easily shift to distance working, minimizing in that way their exposure to contagion. On the contrary, less skilled and lower income workers may not get this opportunity to choose (Honey-Roses et al., 2020). This topic has been touched also by Almagro and Hutchinson (2020) who studied the relationships between working categories and COVID-19 spread, underlining that shares of workers in the science field category, legal occupations, and law enforcement demonstrated to have a negative correlation with the percentage of positive cases in New York neighbourhoods. This trend has also been observed by a Canadian Study (Savage and Turcotte (2020), that underlines that usually, high education workers are more likely to switch to telework and then reduce their exposure to infection. Nonetheless, in this context, another important element is the feasibility of some jobs from home, with substantial variations across working categories.

That said, the critical observation of these other socio-economic aspects (specifically: Income, Low education level, Unemployed people, Races), will be presented in the attachment section, since some methodological aspects cannot be ignored:

- The outcomes of this part of the simple linear regression study may enter into contradiction with those of the second part (presented further), related to the more interesting and useful multiple regression analysis. This means that, as previously pointed out among the limitations of the single linear regression, the results of the simple L.R. were just very partial (and inaccurate, in this case);
- The kinds of information covered by these socio-economic features (income, education, race, and so on) can actually be relevant when looking at the US metropolitan counties system-as-a-whole, but when isolating them one by one, the risk

for this scale of analysis is to lose part of their real weight and meaning in time of COVID-19. More directly, the city scale would have fit these features better (yet opening then to other critical issues), while US metropolitan scale risks to alter their role (in both negative and positive ways);

- Even less than previous features, reading results from simple linear regression of these variables may not bring to any logical results relationship, once again because the US County scale of analysis is not adequate for this level of interpretation.

After these considerations, the analytical part developing the multiple regression analysis will be presented, with new methods and outcomes included.

4.3.2 Multiple linear regression analysis and logarithmic regression analysis

The application of simple regression analysis in the previous paragraph to explain the relationship of the dependent variable y as a function of a single independent variable x, has undoubtedly some limitations. Firstly, using this method it becomes very hard to draw direct conclusions about how y affects x: the assumption that all other factors influencing y are uncorrelated with x is often improbable.

Moreover, multiple regression analysis allows to openly monitor also other factors that simultaneously affect the dependent variable. Thus, since this ability to collect many explanatory variables that may be linked, with multiple regression it is possible to insinuate causality where simple regression would be ambiguous. Not only, having several factors to explain y into play, multiple regression analysis is also useful to create a solid model for predicting the dependent variable.

Another advantage relates to the number of relationships appearing in the model since in the simple regression model, only one function of a single variable can be included in the equation, while the multiple regression model is more open and flexible. In the linear regression model, the coefficient β directly reflects the change in Y for a one-unit change in X. No additional interpretation is needed beyond the estimate β^ of the coefficient itself. This literal interpretation will remain when variables have been logarithmically transformed, but usually there is reason to interpret the changes not in log-units but rather in percentage changes.

An important aspect to consider, especially when developing multiple regression analysis, refers to the already mentioned presence, among some counties, of possible outliers which may influence the analysis trends. In statistical terms, an **outlier** is a data point that differs considerably from other observations and somehow "stands out" for this difference, also in graphical terms. An outlier may be related to variability in the measurement, to a different reference framework, or it may suggest experimental error, which can be sometimes excluded from the data set. Since an outlier can cause serious problems in statistical analyses and interpretations, in these operative steps it is carefully treated. More specifically, along this part of the work, after observing the outcomes of the multiple regression analysis applied to the whole set of county values, the need to exclude some outliers emerged quite clearly. This evidence led then to a second round of analysis with related outcomes-interpretation. The differences between the two versions (with and without the so-called outliers) will be presented along the chapter, so as to better show the influence of these elements in the regression.

Another methodological aspect refers to the addition, starting from the already mentioned multiple linear models, of the logarithmic transformations of variables, which correspond to a very common way to handle situations where a non-linear relationship exists between the independent and dependent variables. Using the logarithm of one or more variables instead of the un-logged form makes the effective relationship non-linear, while still preserving the linear model. Logarithmic analysis is also a convenient means of transforming a highly distorted variable into one that is more approximately normal. In this case, the interpretation refers to an expected percentage change in Y when X increases by some percentage.

That clarified, since it is evident that some phenomena described depend on more than two variables, in this second phase, the work passes to the more sophisticated "multiple linear regression and logarithmic regression" which are used to explain the relationship between one dependent variable and two or more independent ones. Thus, as a priority, in this part of the work, the trend of COVID-19 cases may be explained by firstly addressing the role of population size and density in connection to COVID-19 cases and deaths, in each US metropolitan county.

Multiple regression analysis is one of the most common forms of linear regression analysis, which is used to explain the relationship between one continuous dependent variable and two or more independent variables. More directly, multiple regression predicts the value of Y for given values of $X_1, X_2, \ldots, X_k$. It is considered a powerful technique to study the individual influence of several variables on a certain value, phenomenon or dynamic analysed. As already mentioned for the single linear regression model, in this case the variable to be predicted/examined in its trend is known as the "dependent variable", while those whose values are already known are named "independent variables". This method allows to identify the overall fit of the model and the relative influence of each predictor to the total variance observed.

The equation of multiple regression is given by:

$$Y = b_0 + b_1 X_1 + b_2 X_2 + \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots + b_k X_k + u$$

Where:

b_0 is the intercept and $b_1, b_2, \ldots, b_k$ are similar to the slope in linear regression and thus are also-called regression coefficients. They can be meant as a slope and thus, if $b_i = 3$, it would mean that Y will increase by 3 units if X_i increases by 1 unit.

Multiple regression analysis is also useful to generalize functional correlations between variables. Once a multiple regression equation is created, it is possible to check "how good it is" (in terms of predictive ability) by studying the coefficient of determination (R^2). In regression terms, the R^2 coefficient is a statistical measure of how well the regression predictions estimate the real points. In other terms, R^2 indicates how well the independent variables (x) are able to predict the values of the dependent variable (y) well. R^2 always lies between 0 and 1. An R^2 of 1 indicates that the regression prognostications perfectly fit the data. Thus, the closer R^2 is to 1, the better are the model and its prognostications.

In addition to these observations (further explained with more details), the work then improves the data-analysis and interpretation with other statistical observations, which turn useful to statistically investigate the correlations between the independent variables. This further step helps to explain the results of linear and multiple regressions not only for the entire model but also for the single independent variables addressed. In fact, due to complicated relations in place (further explained), the multiple regression model shows some limitations of the collected data and their direct links with COVID-19 variables. Therefore, once the multiple regression analysis is presented and discussed, then the work investigates the presence of possible relationships between the (so-called) independent variables (or "predictors"), which may depend on some characteristics of the sample. In particular, two further statistical tests will be proposed, in order to address the topics of **Collinearity** and **Multicollinearity**.

The first one is a method to verify the existence of a linear relationship between two variables. It involves two columns of independent variables (considered then as "two ranges" of cells or just a "matrix") expressed by numerical values. Even though all the variables will be tested (with specific focus on the relationships between population size and all the other independent variables, and between density and all the other independent variables), only those worthy of attention will be presented, also in accordance with the most relevant and significant results obtained from the multiple regression analysis. There is a linear relationship if, as the data of one of the two columns changes, the data of the other also vary in a linear way. Said differently, there is a sort of "pattern" that binds one variable to the other, one column to another, following the behaviour of a straight line. If a link like that one is observed, then a relationship between the data can be recognized. In statistical terms, there are several types of correlation coefficients, but the most applied, as reported below, is the so-called "**Pearson's Correlation**" (also "Pearson's R"), together with the "**Student's t-test**".

The second method instead aims to determine the amount of "multicollinearity" in a set of multiple regression variables, through the application of one of the possible methods to detect this condition: the **Variance Inflation Factor (VIF),** supported by the **correlation matrix** of the data. In general, multicollinearity refers to a condition where there is an inter-association between independent (also-called "explanatory" or "predictors") variables in a multiple regression model. In mathematical terms, the VIF refers to the ratio of the overall model variance to the variance of a model that contains only that single independent variable. This value is estimated for every independent variable and, in case it is high, it means that the independent variable under study is highly collinear with the other variables in the model.

This condition can also be observed in the correlation matrix, which highlights bivariate relationships between predictors. The VIF estimation is useful as while multicollinearity does not minimize the explanatory capacity of the model, on the contrary it reduces the statistical importance of the independent variables of the model.

To develop these calculations and charts, Rstudio-Software (in a first phase) and Excel (in the developing one) have been used, and the outcomes will be presented and commented below.

Multiple regression analysis

The **multiple regression analysis** has the role, within this empirical assessment, to put the stress on some spatial variables and how they interact not only with the virus (as already analysed with the single regression) but also within each-others. This is interesting and useful, but on the other side can also be risky because when two (or more) features have any forms of dependency, then Rstudio-Software and Excel-Regression function do not give any more attention to them, even when their singular role is relevant for other analysis. Another problem arises when one or more outliers somehow influence the model, with their "uncommon" and "off-scale" values. Thus, because of these considerations, when applying the multiple regression analysis in the US metropolitan county context, some of the indicators previously considered relevant did not emerge any more from the R outputs or, in some cases, they seem counterintuitive.

To better express the single steps of the multiple regression analysis, in the coming sub-paragraphs a distinction will be made between linear and log-log experiments, so as to define the best result-selection and prioritize the more reliable regression outputs. In this phase, a distinction will also be made between the original data-set and the "cleaned" data-set, meant as the data-set where outliers have been eliminated and not considered in the regression analysis. About the linear-logarithmic and logarithmic-linear analysis, the **outputs will not be presented** here, since their quality was too low and not worthy of attention. As previously mentioned, in this analysis, usually three factors are considered:

- $\mathbf{R^2}$: the **coefficient of determination**, which explains the proportion of the total variance of the y values around the mean of y that is explained by the regression model. Usually, the closer R^2 is to 1, the better are the model and its projections. However, literature suggests that in some study fields, like human behavioural sciences, it is normal to observe R^2 values below 50%. This does not mean that the regression model is not good but just that, by its nature, the dependent variable under observation depends on many different factors, many of which have not been measured yet.

- **Coefficient**: the **size of the coefficient** for each independent variable provides the size of the effect that each variable is having on the dependent variable, and the coefficient-sign (positive or negative) highlights the direction of the effect. More specifically, in regressions with multiple independent variables, the coefficient points out how much the dependent variable is expected to increase when that independent variable increases by one, keeping all the other independent variables constant.

- **p-value**: the **probability value** clarifies how likely it is that the data in the model could have occurred under the null hypothesis. The *p*-value can be considered a proportion: if the *p*-value is 0.05, that means that 5% of the time it is possible to observe a test statistic at least as extreme as the one found if the null hypothesis was true. Statistical significance is another way to state that the p-value of a statistical test is small enough to reject the null hypothesis of the test. Usually, the most common threshold is $p < 0.05$; thus, in this research context, only variables with $p < 0.05$ will be considered.

Once these results are presented, then the other overmentioned statistical tests will be presented, to better investigate the correlations between the independent variables.

A.1 Multiple Linear Regression where the dependent variable (Y) = COVID-19 cases (original dataset with all lines included)

Starting from these general considerations, in the first sample of multiple regression analysis, the following data observe the relationship between COVID-19 cases (as the dependent variable) and all the other variables (considered as the independent variables), putting strong attention to the two features of population size and density. According to the Excel "Regression" function, the outcomes highlight (Figure 11):

OUTPUT RIEPILOGO_Multiple Regression where Y = Cases

Statistica della regressione	
R multiplo	0,986494064
R al quadrato	0,973170539
R al quadrato corretto	0,972756869
Errore standard	10661,40404
Osservazioni	923

ANALISI VARIANZA

	gdl	SQ	MQ	F	Significatività F
Regressione	14	3,7E+12	2,7E+11	2352,528098	0,000000000
Residuo	908	1E+11	1,1E+08		
Totale	922	3,8E+12			

	Coefficienti	ore standc	Stat t	Valore di significatività	Inferiore 95%	periore 95	eriore 95,(	Superiore 95,0%	
Intercetta	-14333,56081	4256,55	-3,3674	0,000790651	-22687,37964	-5979,7	-22687	-5979,741989	
Pop	0,012936106	0,01721	0,75185	0,4523374	-0,020831555	0,0467	-0,0208	0,046703767	
Den	-0,59368571	0,11741	-5,0566	0,0000005163	-0,824108329	-0,3633	-0,8241	-0,363263091	*
Inc19	-0,079940582	0,03161	-2,5291	0,011604225	-0,141974711	-0,0179	-0,142	-0,017906452	*
Unem20	0,254642193	0,07809	3,2608	0,001152341	0,10138059	0,4079	0,10138	0,407903796	*
AHS	-55068,40752	16609,4	-3,3155	0,000951039	-87665,62533	-22471	-87666	-22471,1897	*
AHSo	49504,45996	11890,9	4,16321	0,000034368	26167,53274	72841,4	26167,5	72841,38718	*
AHSr	12066,45822	5349,22	2,25574	0,02432405	1568,189379	22564,7	1568,19	22564,72706	*
Wh	0,126886783	0,02496	5,08456	0,0000004476	0,077909997	0,17586	0,07791	0,175863569	*
BAA	0,098886574	0,02533	3,90397	0,000101632	0,04917488	0,1486	0,04917	0,148598268	*
As	-0,098596301	0,02643	-3,731	0,000202564	-0,150459895	-0,0467	-0,1505	-0,046732707	*
ComF	-0,049607293	0,0358	-1,3857	0,166186936	-0,119867928	0,02065	-0,1199	0,020653341	
Pov19	-0,239666233	0,04025	-5,9541	0,0000000037	-0,318664082	-0,1607	-0,3187	-0,160668384	*
LEd	0,461174724	0,03505	13,159	0,00000000000	0,392393348	0,52996	0,39239	0,529956099	*
HEd	-0,018616631	0,02205	-0,8444	0,398694121	-0,061888335	0,02466	-0,0619	0,024655073	

Figure 11 - Multiple linear regression analysis where Y: COVID-19 cumulative cases (Source: personal elaboration)

Considering only those lines where the p-value (*valore di significatività* in the Figure 11) is worth of statistical significance ($p < 0.05$), it is possible to point out the significant and negative role of density in relation to COVID-19 cases. This means that at the US metropolitan County level, COVID-19 cases decrease in those contexts where density is higher. More directly, observing the Coefficient value, it is possible to state that as the population density increases by one unit, a decrease of 0.59 positive cases of COVID-19 is observed. However, since this observation refers to the third pandemic wave, occurring in the 2021 Summer, there is slight reason to sustain that, in line with the growing literature on the topic, density has probably been crucial and sometimes lethal in urbanized contexts just at the very beginning of the pandemic outbreak. After this peak, updated data suggest that the denser settings tend to contain the virus spread more. Clearly, these data do not represent a projection for the future – where trends may change again – but reflect a trend where the cumulative (and thus, evolving) number of cases are combined with the density status.

Passing to the other variable addressed (population size), nothing can be commented in this context, since the p-value is not statistically relevant, meaning its uninfluential role in this specific observation (also the Coefficient value covers a very low influence on the model).

On the contrary, it seems that the Average Household Size based on both owners (AHSo) and renters (AHSr) had a heavy and positive role in rising the virus-cases, in contrast with the negative role covered by the Median Incomes (Inc19), whose rise leads to a decrease of COVID-19 cases. Observing then the Low levels of Education (Led), it seems that the effects on the virus-positivity are strong.

A.2 Multiple Linear Regression where the dependent variable (Y) = COVID-19 cases (the outliers have been eliminated from the dataset)

Starting from the previous regression model considering the whole dataset, in the following analysis some outliers have been eliminated from the sample, so as to reduce the risk of anomalies and "distant" observations. Thus, similarly to A.1, the following data show the relationship between COVID-19 cases (as the dependent variable) and all the other variables (considered as the independent variables), putting strong attention to the two features of population size and density. According to the Excel "Regression" function, free of all outliers, the outcomes highlight (Figure 12):

OUTPUT RIEPILOGO_Multiple Regression where Y = Cases and X = Variables (NO Outliers among independent variables)

Statistica della regressione	
R multiplo	0,939374465
R al quadrato	0,882424386
R al quadrato corretto	0,879922777
Errore standard	3224,948049
Osservazioni	673

ANALISI VARIANZA

	gdl	*SQ*	*MQ*	*F*	*Significatività F*
Regressione	14	5,14E+10	3,67E+09	352,742755	1,2103E-294
Residuo	658	6,84E+09	10400290		
Totale	672	5,82E+10			

	Coefficienti	*rore standa*	*Stat t*	*Valore di significatività*	*Inferiore 95%*	*periore 95*	*feriore 95,C*	*Superiore 95,0%*	
Intercetta	-13680,80006	2152,9	-6,35459	0,000000000	-17908,18227	-9453,42	-17908,2	-9453,417858	
Pop	-0,081874727	0,019071	-4,29312	0,000020271	-0,119322375	-0,04443	-0,11932	-0,04442708	***
Den	2,013040304	0,987444	2,038637	0,041885529	0,074118383	3,951962	0,074118	3,951962226	*
Inc19	-0,002946583	0,019008	-0,15502	0,876852183	-0,040269485	0,034376	-0,04027	0,034376319	
Unem20	-0,48333129	0,125195	-3,86064	0,000124251	-0,729160595	-0,2375	-0,72916	-0,237501986	***
AHS	-8203,680663	7290,976	-1,12518	0,260921819	-22520,06394	6112,703	-22520,1	6112,702615	
AHSo	9873,105615	5221,346	1,890912	0,059075159	-379,4036862	20125,61	-379,404	20125,61492	
AHSr	3339,740728	2304,338	1,449328	0,147722479	-1185,001101	7864,483	-1185	7864,482557	
Wh	0,097697856	0,020168	4,844125	0,000001587	0,05809583	0,1373	0,058096	0,137299881	***
BAA	0,103671896	0,0219	4,733792	0,000002700	0,060668819	0,146675	0,060669	0,146674972	***
As	-0,192812919	0,063525	-3,03523	0,002498379	-0,317549048	-0,06808	-0,31755	-0,068076791	**
ComF	0,223447817	0,028383	7,872724	0,000000000	0,167716571	0,279179	0,167717	0,279179063	***
Pov19	0,111701699	0,040769	2,739851	0,006313339	0,031648158	0,191755	0,031648	0,191755241	**
LEd	0,277210428	0,056831	4,877833	0,000001347	0,165619133	0,388802	0,165619	0,388801724	***
HEd	-0,072417145	0,02432	-2,97766	0,003011408	-0,120171681	-0,02466	-0,12017	-0,024662609	**

Figure 12 - Multiple linear regression analysis where Y: COVID-19 cumulative cases and with NO outliers among independent variables (Source: personal elaboration)

Considering only those lines where the p-value (*valore di significatività* in the Figure 12) is worth of statistical significance ($p < 0.05$), it is possible to firstly point out the slightly negative role of population size in relation to COVID-19 cases and the slightly positive role of population density. This condition is in contrast with the previous one containing the whole dataset. More specifically, observing the Coefficient values, it is possible to state that as the population size increases by one unit, a small decrease of -0.08 positive COVID-19 cases is provoked, while as the population density increases by one unit, an increase of 2,01 positive cases of COVID-19 is observed. Nonetheless, because this observation refers to the third pandemic wave of Summer 2021, there is reason to sustain that the role of density appears quite limited in the distribution of contagion, and the same – despite with slight negative sign – can be said for population. In any case, the small positive relationship observed between density and COVID-19 cases might link to the period of the year: the summer-time offers actually several occasions, especially among youngers, to meet by person, to fail in following social distancing rules, and to maintain the same “working-habits” also during holiday time. Parallelly, the small negative relationship referred to population size and COVID-19 cases might be referred to the summer condition of some metropolitan areas, when they remain empty for the holiday-time.

Passing to other interesting variables it seems that the presence of Commuting flows (ComF), Poverty levels (Pov19) and Low Levels of Education (Led) leads to an increase of COVID-19 cases, confirming what already observed in the previous analysis and sustained by literature.

B.1 Multiple Linear Regression where the dependent variable (Y) = COVID-19 deaths per capita (original dataset with all lines included)

The following data observe the relationship between COVID-19 deaths per capita (as the dependent variable) and all the other variables (considered as the independent variables), putting strong attention to the two features of population size and density. According to the Excel "Regression" function, the outcomes highlight (Figure 13):

OUTPUT RIEPILOGO _Multiple Regression where Y = Deaths Per Capita

Statistica della regressione	
R multiplo	0,465351234
R al quadrato	0,216551771
R al quadrato corretto	0,204472173
Errore standard	70,71987268
Osservazioni	923

ANALISI VARIANZA

	gdl	*SQ*	*MQ*	*F*	*Significatività F*
Regressione	14	1255221	89658,65	17,92706733	1,04735E-39
Residuo	908	4541181	5001,3		
Totale	922	5796402			

	Coefficienti	*ore standc*	*Stat t*	*Valore di significatività*	*Inferiore 95%*	*ıperiore 95*	*eriore 95,(*	*ıperiore 95,0%*	
Intercetta	165,5303907	28,2348	5,862637	0,000000006373	110,1173324	220,9434	110,1173	220,9434	
Pop	0,000020297	0,000114	0,177837	0,858890935650	-0,000203693	0,000244	-0,0002	0,000244	
Den	-0,000601855	0,000779	-0,7728	0,439842135618	-0,002130308	0,000927	-0,00213	0,000927	
Inc19	-0,002681775	0,00021	-12,7906	0,000000000000	-0,003093263	-0,00227	-0,00309	-0,00227	*
Unem20	0,001284506	0,000518	2,479722	0,013328909746	0,000267882	0,002301	0,000268	0,002301	*
AHS	245,9519389	110,1743	2,23239	0,025832387580	29,72609429	462,1778	29,72609	462,1778	*
AHSo	-92,80356008	78,87572	-1,17658	0,239671739276	-247,6034828	61,99636	-247,603	61,99636	
AHSr	-83,56645831	35,48276	-2,35513	0,018728231277	-153,2042127	-13,9287	-153,204	-13,9287	*
Wh	8,95854E-05	0,000166	0,541187	0,588511569667	-0,00023529	0,000414	-0,00024	0,000414	
BAA	0,000143417	0,000168	0,853576	0,393564943161	-0,000186334	0,000473	-0,00019	0,000473	
As	-0,000227041	0,000175	-1,29522	0,195574820218	-0,000571066	0,000117	-0,00057	0,000117	
ComF	-0,000462424	0,000237	-1,94728	0,051809106247	-0,000928481	3,63E-06	-0,00093	3,63E-06	
Pov19	-0,000820747	0,000267	-3,07393	0,002175704139	-0,00134476	-0,0003	-0,00134	-0,0003	*
LEd	0,000546884	0,000232	2,352474	0,018861579543	9,06395E-05	0,001003	9,06E-05	0,001003	*
HEd	0,000494887	0,000146	3,383781	0,000745544716	0,000207854	0,000782	0,000208	0,000782	*

Figure 13 - Multiple linear regression analysis where Y: COVID-19 deaths per capita (Source: personal elaboration)

Unfortunately, it is not possible to make any considerations about population size and density, as the p-value (*valore di significatività* in the Figure 13) are not worthy of statistical significance ($p < 0.05$). This means that there is no relevant correlation between these two independent variables and the COVID-19 fatality per capita in the context of US metropolitan counties. In any case, from the Coefficient-sign observation, it is possible to see a slight negative direction, meaning again an inverse trend – despite not significant from a statistical point of view – when integrating population density and COVID-19 fatality.

The situation is different for the Average Household Size (AHS), whose increase seems to have a positive impact on the number of deaths per capita, in line with the median Incomes (Inc19). The same can also be noticed for the Unemployment feature (Unem20), whose increase causes a small deaths improvement. Interestingly, at this level the weight of different racial groups does not seem to influence, from a statistical point of view, the deaths-behaviour. A possible explanation is linked to the scale of observation: in case of a deeper level of analysis, as an urban or neighbourhood scale, the relationships with ethnic minorities may result more evident.

B.2 Multiple Linear Regression where the dependent variable (Y) = COVID-19 deaths per capita (the outliers have been eliminated from the dataset)

The following data observe the relationship between COVID-19 deaths per capita (as the dependent variable) and all the other variables (considered as the independent variables), putting strong attention to the two features of population size and density. According to the Excel "Regression" function, the outcomes highlight (Figure 14):

OUTPUT RIEPILOGO_Multiple Regression where Y = Deaths PC and X = Variables (NO Outliers among independent variables)

Statistica della regressione	
R multiplo	0,554639962
R al quadrato	0,307625487
R al quadrato corretto	0,292894115
Errore standard	60,16457316
Osservazioni	673

ANALISI VARIANZA

	gdl	*SQ*	*MQ*	*F*	*Significatività F*
Regressione	14	1058251	75589,38	20,882337	4,9175E-44
Residuo	658	2381813	3619,776		
Totale	672	3440064			

	Coefficienti	*rore standa*	*Stat t*	*Valore di significatività*	*Inferiore 95%*	*uperiore 95*	*eriore 95,0*	*Superiore 95,0%*	
Intercetta	287,6820468	40,16446	7,162602	0,00000000	208,8160799	366,548	208,8161	366,5480136	
Pop	-0,00028726	0,000356	-0,80739	0,41973636	-0,000985883	0,000411	-0,00099	0,000411362	
Den	0,027692016	0,018422	1,503224	0,13326097	-0,008480477	0,063865	-0,00848	0,063864509	
Inc19	-0,00208844	0,000355	-5,88947	0,00000001	-0,002784735	-0,00139	-0,00278	-0,001392144	***
Unem20	0,005601426	0,002336	2,39825	0,01675109	0,001015239	0,010188	0,001015	0,010187614	*
AHS	382,2568376	136,0203	2,810292	0,00509681	115,1706471	649,343	115,1706	649,3430282	**
AHSo	-256,900804	97,40934	-2,63733	0,00855347	-448,1714342	-65,6302	-448,171	-65,6301737	**
AHSr	-125,107883	42,98968	-2,91018	0,00373421	-209,521386	-40,6944	-209,521	-40,69438058	**
Wh	4,01919E-05	0,000376	0,106819	0,91496475	-0,000698623	0,000779	-0,0007	0,000779007	
BAA	0,000515706	0,000409	1,262211	0,20732001	-0,000286559	0,001318	-0,00029	0,00131797	
As	-0,00379995	0,001185	-3,20638	0,00140924	-0,006127027	-0,00147	-0,00613	-0,001472877	**
ComF	0,000165071	0,00053	0,311746	0,75533258	-0,000874651	0,001205	-0,00087	0,001204792	
Pov19	-0,00127324	0,000761	-1,67401	0,09460389	-0,002766714	0,00022	-0,00277	0,000220241	
LEd	0,005107037	0,00106	4,816906	0,00000181	0,003025191	0,007189	0,003025	0,007188882	***
HEd	-0,00046891	0,000454	-1,03348	0,30175989	-0,001359814	0,000422	-0,00136	0,000422001	

Figure 14 - Multiple linear regression analysis where Y: COVID-19 deaths per capita and with NO outliers among independent variables (Source: personal elaboration)

Firstly, with the outliers elimination, it has to be underlined that di R^2 value gains a bit of consistency and reliability, still remaining below the attention values. Secondly, in line with the previous analysis, also in this case it is not possible to make any considerations about population size and density, as the p-value (*valore di significatività* in the Figure 14) are not worthy of statistical significance ($p < 0.05$). This means that, even with the elimination of the outliers, there is not relevant correlation between these two independent variables and the COVID-19 fatality per capita in the context of US metropolitan counties. In any case, from the Coefficient-sign observation, it is possible to see a slight negative direction, meaning again an inverse trend – despite not significant from a statistical point of view – when integrating population size and COVID-19 fatality.

The situation is different for the Low Education Levels (LEd), whose small increase seems to have a small positive impact on the number of deaths per capita, in line with the Unemployment level (Unem20), whose increase causes a small deaths improvement. On the contrary, small decreases in terms of Income levels are linked to an increase in victims.

C.1 Logarithmic Regression where the dependent variable (Y) = LOG COVID-19 cases (original dataset with all lines included)

In this analysis (Figure 15), the regression of the log of COVID-19 cases on the log of the selected independent variables is presented. Despite the R^2 is quite close to 1, and despite the coefficient suggests that as the population size increases by 1%, cases decrease by 0,05%; and that similarly, with the 1% increase in density, the decrease in positive cases of COVID-19 is 0.01%, the two features under observation (population size and density), cannot be considered relevant in this study because of their too high p-value. In any case, from the Coefficient observation, the negative direction emerges in both cases, thus reporting a weak negative influence of the two logarithmic variables and the disease cases.

OUTPUT RIEPILOGO_Multiple Regression where Y = LOG Cases

Statistica della regressione	
R multiplo	0,9649645
R al quadrato	0,93115649
R al quadrato corretto	0,93009503
Errore standard	0,11282154
Osservazioni	923

ANALISI VARIANZA

	gdl	*SQ*	*MQ*	*F*	*Significatività F*
Regressione	14	156,325	11,1661	877,2381402	0,00000000
Residuo	908	11,5577	0,01273		
Totale	922	167,883			

	Coefficienti	*ore standa*	*Stat t*	*Valore di significatività*	*Inferiore 95%*	*periore 95*	*eriore 95,0*	*eriore 95,0%*	
Intercetta	-0,8905982	0,5623	-1,5838	0,113578393762	-1,99416319	0,21297	-1,9942	0,21297	
Log Pop	-0,0499811	0,13489	-0,3705	0,711067660492	-0,314708821	0,21475	-0,3147	0,21475	
Log Den	-0,0115207	0,01022	-1,1268	0,260127514609	-0,031586756	0,00855	-0,0316	0,00855	
Log Inc19	-0,2150091	0,1223	-1,758	0,079086834383	-0,455040886	0,02502	-0,455	0,02502	
Log Unem20	-0,1249783	0,04153	-3,0093	0,002691183738	-0,206486646	-0,0435	-0,2065	-0,0435	*
Log AHS	0,73747709	1,12439	0,65589	0,512061111993	-1,469231354	2,94419	-1,4692	2,94419	
Log AHS	0,73132536	0,81653	0,89565	0,370679094078	-0,871187409	2,33384	-0,8712	2,33384	
Log AHSr	0,04476949	0,36549	0,12249	0,902536358430	-0,672531128	0,76207	-0,6725	0,76207	
Log Wh	0,43026141	0,0587	7,32982	0,000000000001	0,315057713	0,54547	0,31506	0,54547	*
Log BAA	0,09866036	0,01197	8,24309	0,000000000000	0,075170526	0,12215	0,07517	0,12215	*
Log As	-0,1601591	0,01788	-8,9597	0,000000000000	-0,195241325	-0,1251	-0,1952	-0,1251	*
Log ComF	0,76471458	0,10695	7,14999	0,000000000002	0,554810186	0,97462	0,55481	0,97462	*
Log Pov19	0,0996557	0,06662	1,49591	0,135023356421	-0,031088578	0,2304	-0,0311	0,2304	
Log LEd	0,0317354	0,03662	0,86655	0,386415864169	-0,040139323	0,10361	-0,0401	0,10361	
Log HEd	-0,007206	0,05096	-0,1414	0,887581576710	-0,107219914	0,09281	-0,1072	0,09281	

Figure 15 - Multiple logarithmic regression analysis where Y: LOG COVID-19 cumulative cases (Source: personal elaboration)

More interestingly, in this case the logarithmic value highlights the role of racial groups on COVID-19 positivity, highlighting that as the white population increases by 1%, cases increase by 0,43%; and that similarly, with the 1% increase of Black and African people, the rise in positive cases of COVID-19 is 0.1%. On the contrary, the effects of Asian groups appear negative, as when they increase by 1%, then COVID-19 cases decrease by 0,16.

Another interesting reflection comes from the Commuting Flows (ComF), whose increase by 1% seems to provoke a cases-increase by 0,76%. The daily commuting habits may explain the rapid circulation in some areas, especially for longer distances[16]. Indeed, Carozzi et al. (2020) state that commuting patterns and, even more, the use of public transport offers a higher degree of human exposure and hence, to contract the disease. This is particularly realistic for those working categories that travel more frequently or for whom the working-from-home option was not applicable. This data confirms that the use of public transport seems to be positively correlated to the virus circulation, enforcing then the findings from the single regression analysis and, mostly, aligning to the recent literature on the topic (Hamidi et al., 2020; Chu et al., 2017). Also in this case however, it would be interesting to repeat the analysis with updated data about the use of public transport and presence of commuters also during and after the pandemic, but in any case, the "state of the art" about how much the population from US metropolitan counties use public transport is enough to state that this habit has greatly contributed – especially for some working categories – to the COVID-19 circulation within the counties.

C.2 Logarithmic Regression where the dependent variable (Y) = LOG COVID-19 cases (the outliers have been eliminated from the dataset)

Passing then to the second version of the same multiple regression presented in C.1, but without including the so-called "outliers" of each independent variable, a new version of multiple linear regression where Y = LOG COVID-19 cases is presented. According to this second level of analysis, the outcomes reveal what follows (Figure 16):

[16] However, as already observed in Chapter 3, when mentioning Commuting Flows in this thesis, it is important to remember that this feature contains some limitations referred to the coexistence, under the same data, of several methods of transportation (the most used among private, public, sustainable method). This means that sometimes, there may be a lower estimate of public transit commuting if a worker drives a superior distance than she/he travels by public transit.

OUTPUT RIEPILOGO_Multiple Regression where Y = LOG Cases (NO Outliers among independent variables)

Statistica della regressione	
R multiplo	0,919170822
R al quadrato	0,844874999
R al quadrato corretto	0,841574467
Errore standard	0,107556148
Osservazioni	673

ANALISI VARIANZA

	gdl	*SQ*	*MQ*	*F*	*Significatività F*
Regressione	14	41,45787	2,961277	255,9814648	3,7145E-255
Residuo	658	7,611958	0,011568		
Totale	672	49,06983			

	Coefficienti	*rore standa*	*Stat t*	*Valore di significatività*	*Inferiore 95%*	*uperiore 95%*	*feriore 95,0%*	*eriore 95,0%*	
Intercetta	-1,119737596	0,702966	-1,59288	0,111668143	-2,500064125	0,260589	-2,50006	0,260589	
OUT_Log POP	-0,046418622	0,175962	-0,2638	0,792017374	-0,391933468	0,299096	-0,39193	0,299096	
OUT_Log Den	0,037364467	0,015292	2,443358	0,014813035	0,00733696	0,067392	0,007337	0,067392	*
OUT_Log Inc19	-0,120216882	0,154546	-0,77787	0,436924106	-0,423679374	0,183246	-0,42368	0,183246	
OUT_Log Unemo20	-0,07759541	0,049997	-1,552	0,121141895	-0,175768088	0,020577	-0,17577	0,020577	
OUT_Log AHS	-1,105084201	1,47025	-0,75163	0,45254212	-3,992030555	1,781862	-3,99203	1,781862	
OUT_Log AHSo	1,566595351	1,062422	1,474551	0,14081157	-0,519550655	3,652741	-0,51955	3,652741	
OUT_Log AHSr	0,829163327	0,445519	1,861119	0,063173099	-0,045646281	1,703973	-0,04565	1,703973	
OUT_Log Wh	0,290558038	0,095571	3,040234	0,002457805	0,102897248	0,478219	0,102897	0,478219	*
OUT_Log BAA	0,050403903	0,016225	3,106558	0,001974224	0,018544889	0,082263	0,018545	0,082263	*
OUT_Log As	-0,09783033	0,022126	-4,42141	0,0000114700	-0,141277387	-0,05438	-0,14128	-0,05438	***
OUT_Log ComF	0,937883905	0,129691	7,231688	0,000000000001330	0,683226049	1,192542	0,683226	1,192542	***
OUT_Log Pov19	0,116021448	0,075199	1,542851	0,123347694	-0,031638244	0,263681	-0,03164	0,263681	
OUT_Log Led	0,024743916	0,044161	0,56031	0,575458504	-0,061969737	0,111458	-0,06197	0,111458	
OUT_Log HEd	-0,145533427	0,058206	-2,5003	0,012651139	-0,259826227	-0,03124	-0,25983	-0,03124	*

Figure 16 - Multiple linear regression analysis where Y: Log COVID-19 cases and with NO outliers among independent variables (Source: personal elaboration)

Considering only those lines where the p-value (*valore di significatività* in the Figure 16) is worth of statistical significance ($p < 0.05$), it is possible to point out the significant and negative role of density in relation to COVID-19 cases. This means that at the US metropolitan County level, excluding any outliers that may have precedingly interfered with the outcomes, COVID-19 cases slightly increase when density is higher. More directly, observing the Coefficient value, it is possible to state that as the population density increases by one unit, a small increase of 0.03 positive cases of COVID-19 is observed. However, since this observation refers to the third pandemic wave, occurring in the 2021 Summer, there is slight reason to sustain that, in line with the growing literature on the topic, density has probably been more determinant and influential in urbanized contexts just at the very beginning of the pandemic outbreak. After this peak, updated data suggest that the denser settings tend to influence less the virus spread. Clearly, these data do not represent a projection for the future – where trends may change again – but reflect a trend where the cumulative (and thus, evolving) number of cases are combined with the density status. Moreover, the outliers elimination from the dataset highlights that density, in this context, does not cover a heavy role in increasing the infection numbers.

Passing to the other variable addressed (population size), nothing can also be added in this context of analysis, since the p-value is not statistically relevant, meaning its uninfluential role in this specific observation.

On the contrary, it seems that the Commuting factor covers a great positive role in rising the virus-cases, in contrast with the negative role covered by the High levels of Education (Led) and the presence of Asian minorities. Surprisingly and differently from the previous analysis, in this "lightened" dataset the role of the commuters in favouring the virus circulation comes particularly on surface, confirming the thesis of other published studies (Almagro and Hutchinson, 2020; Hamidi, 2020; Honey-Roses et al., 2020; Savage and Turcotte, 2020). This role had actually already emerged when studying each indicator singularly, through the single regression analysis, but in this context it has much more meaning.

D.1 Logarithmic Regression where the dependent variable (Y) = LOG COVID-19 deaths per capita (original dataset with all lines included)

The following data show the regression of the log of COVID-19 deaths per capita (as the dependent variable) on the log of the selected independent variables (considered as the independent variables) is presented, putting strong attention on the two features of population size and density (Figure 17). According to the Excel "Regression" function, the outcomes highlight:

OUTPUT RIEPILOGO_Multiple Regression where Y = LOG Deaths PER CAPITA

Statistica della regressione	
R multiplo	0,645209711
R al quadrato	0,416295571
R al quadrato corretto	0,407295723
Errore standard	0,170360264
Osservazioni	923

ANALISI VARIANZA

	gdl	*SQ*	*MQ*	*F*	*Significatività F*
Regressione	14	18,79452096	1,34247	46,25584456	4,79847E-96
Residuo	908	26,35253863	0,02902		
Totale	922	45,14705959			

	Coefficienti	*Errore standard*	*Stat t*	*Valore di significatività*	*Inferiore 95%*	*periore 95*	*eriore 95,0*	*eriore 95,0%*	
Intercetta	2,646935642	0,849076484	3,11743	0,0018817947276	0,980555077	4,31332	0,98056	4,31332	
Log Pop	-0,464475006	0,203679987	-2,2804	0,0228140718513	-0,864213285	-0,0647	-0,8642	-0,0647	*
Log Den	-0,012065035	0,015438705	-0,7815	0,4347240961034	-0,04236473	0,01823	-0,0424	0,01823	
Log Inc19	-0,147881279	0,184679075	-0,8007	0,4234873957497	-0,510328747	0,21457	-0,5103	0,21457	
Log Unem20	0,134352535	0,062712044	2,14237	0,0324289146380	0,011275128	0,25743	0,01128	0,25743	*
Log AHS	3,789500195	1,697828585	2,23197	0,0258603154496	0,457375696	7,12162	0,45738	7,12162	*
Log AHS	-1,797535387	1,232963964	-1,4579	0,1452145031908	-4,217325859	0,62226	-4,2173	0,62226	
Log AHSr	-2,151559727	0,551886903	-3,8986	0,0001038924391	-3,23468195	-1,0684	-3,2347	-1,0684	*
Log Wh	0,267830391	0,088637052	3,02165	0,0025844995446	0,093873082	0,44179	0,09387	0,44179	*
Log BAA	0,155632979	0,018072943	8,61138	0,0000000000000	0,120163381	0,1911	0,12016	0,1911	*
Log As	-0,233956043	0,02699203	-8,6676	0,0000000000000	-0,286930062	-0,181	-0,2869	-0,181	*
Log ComF	0,010552936	0,161499218	0,06534	0,9479148356796	-0,306402207	0,32751	-0,3064	0,32751	
Log Pov19	-0,02919306	0,100593887	-0,2902	0,7717240679555	-0,226616615	0,16823	-0,2266	0,16823	
Log LEd	0,405884812	0,055299991	7,33969	0,0000000000005	0,297354153	0,51442	0,29735	0,51442	*
Log HEd	-0,11025404	0,076950088	-1,4328	0,1522593637520	-0,261274748	0,04077	-0,2613	0,04077	

Figure 17 - Multiple logarithmic regression analysis where Y: Log COVID-19 deaths per capita (Source: personal elaboration)

Despite the R^2 values appearing below 50%, the regression model is not wrong but, because of its nature, it presents a dependent variable related to many different factors, some of which have not been considered in this analysis. In view of this, it can be said that for the first time, the low p-value of the population size variable allows to make some considerations on its effects: as the population size increases by 1%, deaths per capita decrease by 0,46%. On the contrary, density outputs are not worthy of attention in this case because of the poor quality of the regression outcomes. Two other interesting effects are those referred to the Unemployed presence (Unem20) and the Average Household Size (AHS), whose increase by 1% is linked to deaths per capita rises by, respectively, 0,13% and, surprisingly, by 3,7%. Another interesting effect is related to the rise by 1% of Low Education levels (Led), that leads to an increase of deaths per capita by 0,4%.

Once again, these outcomes reflect a situation where socio-economic conditions highly influence the pandemic distribution and its effects on different population categories.

D.2 Logarithmic Regression where the dependent variable (Y) = COVID-19 deaths per capita (the outliers have been eliminated from the dataset)

The following data show the regression of the log of COVID-19 deaths per capita (as the dependent variable) on the log of the selected independent variables (considered as the independent variables) in a dataset where the outliers have been eliminated. Again, the main attention is referred to the two features of population size and density (Figure 18). According to the updated Excel "Regression" function, the outcomes highlight:

OUTPUT RIEPILOGO_Multiple Regression where Y = LOG Deaths PC (NO Outliers among independent variables)

Statistica della regressione	
R multiplo	0,627303144
R al quadrato	0,393509235
R al quadrato corr	0,380605176
Errore standard	0,156386325
Osservazioni	673

ANALISI VARIANZA

	gdl	*SQ*	*MQ*	*F*	*Significatività F*
Regressione	14	10,44129	0,745806	30,49499699	2,53837E-62
Residuo	658	16,0925	0,024457		
Totale	672	26,53379			

	Coefficienti	*rore standa*	*Stat t*	*Valore di significatività*	*Inferiore 95%*	*uperiore 95*	*feriore 95,0*	*eriore 95,0%*	
Intercetta	3,774704449	1,02211	3,693051	0,000239971	1,767713703	5,781695	1,767714	5,781695	
OUT_Log POP	-0,42121556	0,255848	-1,64635	0,100169487	-0,923593138	0,081162	-0,92359	0,081162	
OUT_Log Den	0,043348556	0,022235	1,949573	0,051651468	-0,000311351	0,087008	-0,00031	0,087008	
OUT_Log Inc19	-0,420622548	0,224709	-1,87185	0,061670391	-0,861856125	0,020611	-0,86186	0,020611	
OUT_Log Unemo2	0,157186337	0,072695	2,162262	0,030957686	0,014443549	0,299929	0,014444	0,299929	*
OUT_Log AHS	3,960828499	2,137739	1,852812	0,064356797	-0,236783075	8,15844	-0,23678	8,15844	
OUT_Log AHSo	-2,558030008	1,544758	-1,65594	0,098210384	-5,591280215	0,47522	-5,59128	0,47522	
OUT_Log AHSr	-1,484111848	0,647783	-2,29106	0,022274942	-2,756082465	-0,21214	-2,75608	-0,21214	*
OUT_Log Wh	0,401683692	0,13896	2,890645	0,003971238	0,128825451	0,674542	0,128825	0,674542	**
OUT_Log BAA	0,138052731	0,023591	5,851899	0,00000000767	0,091729818	0,184376	0,09173	0,184376	***
OUT_Log As	-0,162742067	0,032172	-5,05852	0,00000054869	-0,22591396	-0,09957	-0,22591	-0,09957	***
OUT_Log ComF	0,096597062	0,18857	0,512261	0,608640516	-0,273674718	0,466869	-0,27367	0,466869	
OUT_Log Pov19	-0,101076587	0,10934	-0,92443	0,355602788	-0,315773348	0,11362	-0,31577	0,11362	
OUT_Log Led	0,259504891	0,06421	4,041496	0,00005938919	0,133423493	0,385586	0,133423	0,385586	***
OUT_Log HEd	-0,256275727	0,084632	-3,02812	0,002557096	-0,422457126	-0,09009	-0,42246	-0,09009	**

Figure 18 - Multiple linear regression analysis where Y: Log COVID-19 deaths per capita and with NO outliers among independent variables (Source: personal elaboration)

Even though the R^2 value is again below 50%, the regression model is not wrong but, because of its nature, it presents a dependent variable probably "scattered" among other variables and related also to other different factors, some of which have not been considered in this analysis. In view of this, it can be said that the low p-value (low but not worthy of attention in terms of p-value levels) of the population size variable allows to make some considerations on its effects: as the population size increases by 1%, deaths per capita decrease by 0,42%. Similarly, also density outputs cannot be taken into consideration because of the poor quality of the regression outcomes, but in general they seem to be poorly related to a small increase of lethality cases. The most interesting effects are those referred to the presence of Black communities (BAA) and Low Education levels (Led), whose increase by 1% is linked to deaths per capita rises by, respectively, 0,13% and 0,25%.

Once again, also after the outliers exclusion from the dataset, these outcomes reflect a situation where socio-economic conditions highly influence the pandemic distribution and its effects on different population categories.

From these results, it is possible to point out that several socio-economic characteristics cover an active role in the pandemic distribution and that, on the contrary, it is more difficult to find an evident correlation between the population size and density and the COVID-19 variables, considering this scale level, the fragmented policies in place and the institutional context. Quite surprisingly, this condition does not change that much when eliminating the so-called outliers, probably because there are actually several other factors in place that, at the US metropolitan scale, have a greater weight on this dynamic. In fact, at that scale of analysis, it is possible to believe that some aspects are not properly addressed, since their specific and local weight is actually distributed in the whole county surface, sometimes losing the real role (and impact) at a smaller scale on COVID-19. Starting from these results then, it is interesting to add some further observation through the use of other statistical tests, presented below.

4.3.3 Correlation analysis through Pearson and Student's t-tests

As previously clarified, there are various possible methods to search for possible relationships between data. Here in particular, the method for looking for a relationship between data under consideration involves verifying the existence of a linear relationship between two columns (such as between two ranges of cells) of numerical values. There is a linear relationship if, as the data of one of the two columns changes, the data of the other vary in a linear way. It is clear then that if there is this link, there is a relationship between the data. The statistical test mostly used to search for this linear correlation is the **Pearson's correlation**, coupled to **Student's t-test**.

The first test, Pearson's correlation, calculates the value of the linear correlation coefficient, called **r**. The value of r is a number between -1 and 1. The more the value of the coefficient of correlation approaches the extremes (1 or -1), the more the correlation is present, in a positive way if close to 1 (when the value of one of the columns or variables increases, then the value of the other increases too), in a negative form if close to -1 (when the value of one of the columns or variables increases, that of the other decreases). The 0-correlation value indicates the absence of linear correlation, but there may be another type of correlation, non-linear (for example quadratic or otherwise), which this test simply cannot detect.

The second test, the Student's t-test, aims to provide the probability that the eventual relationship, apparently found thanks to the "high" correlation value, is instead due only to chance, to the "biological variability" of the model: it therefore provides the probability of the hypothesis "H0" which, as usual, means "what is measured depends only on chance". In the biomedical field, for instance, probabilities of H0 are considered interesting when <0.05 (5%) or <0.01 (1%).

Thanks to the use of Excel and starting from the most interesting outcomes of the regression models presented in the previous section (A.2, B.2, C.2, D.2 – such as: those models without the outliers), in this section the results of these tests are presented and commented on. Two methodological assets guided this analytical step:

I. The correlation has been studied among independent variables, with focus on the possible correlation on population size and some relevant independent variables on one side, and the possible correlation on population density and some relevant independent variables on the other. This decision allows to maintain the focus on the two selected features, deepening their links with the other independent socio-economic variables in place.
II. The Pearson and t-Student's tests have been processed according to two groups: the Multiple linear regression analysis developed for COVID-19 cases and deaths per capita (without the outliers) (A.2, B.2), and the Logarithmic regression analysis developed for COVID-19 cases and deaths per capita (without the outliers) (C.2, D.2). The outliers-presence is in fact considered an influential factor in the determination of Pearson's correlation, which is in turn mainly a qualitative test.

In terms of results-interpretation, it can be said that from a qualitative point of view, the r values in Pearson's correlation can be divided according to the strength of the association (Marafatto, 2021):

- 0 <r <0.3 weak correlation;
- 0.3 <r <0.7 moderate correlation;
- r> 0.7 strong correlation.

However, in statistical and scientific fields, the qualitative interpretation of Pearson's test is not enough, as those moderate terms ("weak/moderate/strong") are by no means objective. For this reason, Pearson's correlation is often coupled with the t-Student's test, thus estimating the objective probability that the results obtained are simply due to chance. In general, the P value from the t-Student's test considers a minimum of 0.05 (5%) to be acceptable, so for instance in case a t-test shows a P = 0.03, the probability that the result is due to chance is equal to 3% and then the relationship is significant (but this does not mean that it is 97% significant). From these results, it is only possible to state that the "chance" influences the result only by 3%.

Back to the thesis data and multiple regression outcomes, when applying the Pearson's correlation and the t-Student's test, it is possible to state that:

- Within the database used for the **Multiple linear regression analysis developed for COVID-19 cases and deaths per capita (without the outliers)** (A.2, B.2), the strongest correlations refer to population size and some specific variables. More deeply, Pearson's correlation test (coupled with t-Student's test) highlights (a) a very high correlation between population size and unemployed people (r = 0.95) with a very low probability that this correlation occurred by chance; (b) a very high correlation between population size and commuting flows (r = 0.98) with a very low probability that this correlation occurred by chance; (c) a high correlation between population size and poverty levels (r = 0.84) with a very low probability that this correlation occurred by chance; (d) a high correlation between population size and both (separately) white and Asian people (r = 0.98 and r = 0.77, respectively) with a very low probability that this correlation occurred by chance ; and (e) a high correlation between population size and both (separately) education levels (low – r =

0.80 and high – r =0.92) with a very low probability that this correlation occurred by chance (see the Attachment – Section 3 for the Excel results). These data will be also presented and verified in the correlation matrix.

- Within the same database, the feature of density does never appear as "moderately or highly correlated" to any independent variables. So, this means that differently from population size, the density-behaviour has basically no (or just very small) correlation with the other variables in place (see the Attachment – Section 3 for the Excel results). These data will be also presented and verified in the correlation matrix.
- Correlation and causality are not synonyms. In fact, while correlation simply refers to a relationship, causality explicitly applies to situations where action A causes outcome B. Thus, the correlation analysis has nothing to do with the cause-effect condition, which follows other rules, here not addressed. This short clarification can be useful when interpreting the tests' outcomes.
- On the other side, within the **Logarithmic regression analysis developed for COVID-19 cases and deaths per capita (without the outliers)** (C.2, D.2) the strongest correlations refer again to population size and some specific variables. More deeply, Pearson's correlation test (coupled with t-Student's test) highlights (a) a very high correlation between population size and unemployed people (r = 0.95) with a very low probability that this correlation occurred by chance; (b) a very high correlation between population size and commuting flows (r = 0.98) with a very low probability that this correlation occurred by chance; (c) a high correlation between population size and poverty levels (r = 0.83) with a very low probability that this correlation occurred by chance; (d) a high correlation between population size and Asian people (r = 0.83) with a very low probability that this correlation occurred by chance; and (e) a high correlation between population size and both (separately) education levels (low – r = 0.76 and high – r =0.91) with a very low probability that this correlation occurred by chance (see the Attachment – Section 3 for the Excel results). Also in this case, these data will be presented and verified in the correlation matrix.
- Within the same database and similarly to the previous observation, the feature of density only appears as "low or moderate correlated" to any independent variables. So, this means that differently from population size, the density-behaviour has basically

poor or moderate correlation with the other variables in place (see the Attachment – Section 3 for the Excel results). Also in this case, these data will be presented and verified in the correlation matrix.

In general and to conclude, it can be stated that when linear regression highlights the existence of a linear relationship between the "predictors = X" and the "outcome = Y", it is a good condition (Choueiry, 2021). However, when the correlation refers to two independent variables, it is not possible anymore to determine the effect of one while keeping the other constant as the two X vary together. Hence, their coefficients will be less precise and less understandable.

The strong correlation between two independent variables can be problematic when reading the linear model, as it means that two or more predictors are linearly linked to each other. In this case, the situation is mainly referred to the population size variable that influences several other socio-economic variables as, logically, when the amount of people living together grows, then also some specific socio-economic conditions increase.

To better understand this situation, it is worthwhile to address the Multicollinearity condition, in order to deepen the relationship between three or more independent variables.

4.3.4 Multicollinearity: studying Correlation matrix and variance inflation factor (VIF)

As already mentioned, multicollinearity simply describes a condition where there is an inter-association between independent variables in a multiple regression model. In fact, despite an explanatory variable may seem "insignificant" in a multiple regression, on the contrary, it may be significant in a simple regression. In this section, there is reason to deepen the analytical process of the previous section, introducing two other tests.

The first test addresses the topic of collinearity meant as a condition, when running a regression model, where two or more predictors share a strong linear relationship. Collinearity can refer either to the correlation of a pair of independent variables, or to a linear correlation between three or more. While the first case is usually represented through the **Correlation Matrix**, the second one is mainly addressed through the **variance inflation factor (VIF).**

The Correlation Matrix is a good method to identify collinearity. In this thesis context, two matrixes have been developed (Figure 19 and 20): one including the absolute values of each predictor, the other including all the LOG values of each variable.

Correlation Matrix - noLog Independent Variables

	Pop	Den	Inc19	Unem20	AHS	AHSo	AHSr	Wh	BAA	As	ComF	Pov19	LEd	HEd
Pop	1													
Den	0,61717	1												
Inc19	0,284942	0,329935	1											
Unem20	0,945036	0,598881	0,267591	1										
AHS	0,027101	0,04534	0,26375	-0,00914	1									
AHSo	0,088567	0,12069	0,357488	0,04471	0,92748	1								
AHSr	-0,05675	-0,07408	-0,02545	-0,08837	0,811258	0,556658	1							
Wh	0,980414	0,588936	0,337298	0,932155	-0,02053	0,05403	-0,11967	1						
BAA	0,490552	0,417393	-0,1168	0,440484	0,166436	0,126385	0,227334	0,336168	1					
As	0,770434	0,508265	0,336846	0,707748	0,045168	0,135743	-0,05292	0,755881	0,352507	1				
ComF	0,980823	0,634995	0,358808	0,925722	0,002845	0,100653	-0,13339	0,976819	0,442695	0,80114	1			
Pov19	0,835571	0,432632	-0,14749	0,78983	-0,01779	-0,00242	0,040575	0,771285	0,619274	0,630175	0,771068	1		
LEd	0,790319	0,441571	-0,04139	0,766511	0,18624	0,131193	0,249401	0,739124	0,553066	0,494149	0,70452	0,827409	1	
HEd	0,920243	0,598587	0,455033	0,850055	-0,042	0,04813	-0,15047	0,929358	0,371905	0,812859	0,944953	0,677129	0,582613	1

Figure 19 – Correlation Matrix where X: absolute/original values for each independent variable and with NO outliers among independent variables (Source: personal elaboration)

Correlation Matrix - Log Independent Variables

	O_L.POP	O_L.Den	O_L.Inc	O_L.Unem	O_L.AHSo	O_L.AHSr	O._L.AHS	O_L.Wh	O_L.BAA	O_L.As	O_L.ComF	O_L.Pov	O_L.Led	O_L.HEd
O_L.POP	1													
O_L.Den	0,562501	1												
O_L.Inc	0,301672	0,282144	1											
O_L.Unem	0,945771	0,539198	0,300512	1										
O_L.AHSo	0,11221	0,094447	0,350666	0,055466	1									
O_L.AHSr	-0,06291	-0,08541	-0,04033	-0,107196	0,541673	1								
O._L.AHS	0,037818	0,022383	0,252016	-0,012404	0,923015	0,806316	1							
O_L.Wh	0,956754	0,526829	0,396383	0,912183	0,068839	-0,16136	-0,03242	1						
O_L.BAA	0,546584	0,526973	-0,08707	0,486569	0,150303	0,249965	0,186307	0,350329	1					
O_L.As	0,825964	0,502508	0,418135	0,753155	0,18391	-0,04439	0,076052	0,79431	0,472826	1				
O_L.ComF	0,978968	0,578542	0,399969	0,926515	0,122605	-0,15269	0,005628	0,959695	0,499526	0,852177	1			
O_L.Pov	0,828522	0,391276	-0,21232	0,771878	-2,4E-05	0,067978	-0,00872	0,72081	0,645731	0,64681	0,75378	1		
O_L.Led	0,761441	0,413938	-0,10059	0,721143	0,135169	0,279095	0,208428	0,670283	0,613751	0,477872	0,66509	0,815597	1	
O_L.HEd	0,911595	0,558273	0,513164	0,853815	0,059066	-0,19262	-0,05799	0,906675	0,429235	0,870632	0,942687	0,648931	0,508686	1

Figure 20 – Correlation Matrix where X: LOG of each independent variable and with NO outliers among independent variables (Source: personal elaboration)

Understandably, as previously observed through the Pearson Correlation and t-Student's tests, the collinearity as the absolute value of the correlation-coefficients between the "population size" variable and the other predictors is usually quite high (according to Booth et al., 1994, if the pairwise correlations exceed a threshold of 0.5–0.7, collinearity is high) except for the "average household" features. This trend may indicate that within this study context (as commonly happens), collinearity is an intrinsic condition, suggesting that collinear variables are different manifestations of the same underlying process (or latent variable) (Dormann, 2012). More directly, it may be possible to state that when interpreting the COVID-19 diffusion process while addressing demographic and socio-economic conditions like this work, since they are all representations of the sample, they may be all (or partly) highly correlated. However, in this case, the effects of collinearity may have limited impact and the model may keep its reliability as long as the collinearity between variables remains constant (Harrell, 2001). In any case, it is recommended to pay attention in case these predictors would be extrapolated beyond the geographic or environmental range of these sampled data, as the collinearity patterns are likely to change. As stated in fact by literature, collinearity in geographical data may fluctuate across spatial scales, making it complicated to explain at which spatial scale each predictor is acting (Wheeler, 2007).

Once arrived at this analytical step, it becomes clear that since collinearity can also occur between three or more variables, the correlation matrix has some limitations as it cannot be applied to identify all situations of collinearity. Therefore the Variance Inflation Factor (VIF) is introduced.

This second test is usually applied to determine the severity of the multicollinearity in a multiple regression model. It is measured through that formula:

$$VIF_1 = \frac{1}{1 - R^2}$$

…which is calculated for each independent variable and interpreted through these decision criteria (Belsley, 1991; Hair et al., 1995):

- VIF value: less than 5 → multicollinearity severity: low;
- VIF value: between 5 and 10 → multicollinearity severity: medium;
- VIF value: greater than 10 → multicollinearity severity: high.

Detecting multicollinearity is important because while multicollinearity does not reduce the explanatory power of the model, it does reduce the statistical significance of the independent variables. When the severity of multicollinearity is high it creates a problem in the understanding of the multiple regression because all the inputs affect each other. Therefore, they are not totally independent and it is difficult to verify how much the combination of independent variables affects the dependent variable, within the regression model. In statistical terms, a multiple regression model in which there is a high multicollinearity level will limit the estimation of the relationship between each of the independent variables and the dependent variable. Therefore, if the multicollinearity is small/medium, then it does not influence the explanatory variables too much, the variable analysed can be retained in the model and the model itself does not lose its reliability status.

Back to case study, the analysis carried out to estimate the VIF produced the following results (Figure 21 and 22). Again, the calculations were conducted both for the variables in absolute numbers and for the LOG variables.

VIF - noLog Independent Variables						
COVID-19 Cases	**R2**	**VIF**		**COVID-19 Deaths PC**	**R2**	**VIF**
VIF POP	0,879	8,273		VIF POP	0,307	1,443
VIF DEN	0,882	8,452		VIF DEN	0,305	1,439
VIF INCON	0,882	8,505		VIF INCOME	0,271	1,372
VIF UNEM	0,880	8,317		VIF UNEMPL	0,302	1,432
VIF AHS	0,882	8,489		VIF AHS	0,299	1,427
VIF AHSo	0,882	8,459		VIF AHSo	0,300	1,429
VIF AHSR	0,882	8,478		VIF AHSR	0,299	1,426
VIF WH	0,878	8,212		VIF WH	0,308	1,444
VIF BAA	0,878	8,225		VIF BAA	0,306	1,441
VIF AS	0,881	8,388		VIF AS	0,297	1,422
VIF COMf	0,871	7,773		VIF COMf	0,308	1,444
VIF POV	0,881	8,409		VIF POV	0,305	1,438
VIF Led	0,878	8,208		VIF Led	0,283	1,395
VIF Hed	0,881	8,392		VIF Hed	0,307	1,442

Figure 21 – Variance inflation factor (VIF) for each independent variable, where X: absolute/original values for each independent variable and with NO outliers among independent variables (Source: personal elaboration)

VIF - Log Independent Variables						
COVID-19 Cases	R2	VIF		COVID-19 Deaths PC	R2	VIF
VIF L POP	0,845	6,446		VIF L POP	0,391	1,642
VIF L DEN	0,843	6,388		VIF L DEN	0,390	1,639
VIF L INCOME	0,845	6,440		VIF L INCOME	0,390	1,640
VIF L UNEMPL	0,844	6,423		VIF L UNEMPL	0,389	1,637
VIF L AHS	0,845	6,441		VIF L AHS	0,390	1,640
VIF L AHSo	0,844	6,425		VIF L AHSo	0,391	1,642
VIF L AHSR	0,844	6,413		VIF L AHSR	0,389	1,636
VIF L WH	0,843	6,357		VIF L WH	0,386	1,628
VIF L BAA	0,843	6,353		VIF L BAA	0,362	1,567
VIF L AS	0,840	6,260		VIF L AS	0,370	1,587
VIF L COMf	0,833	5,972		VIF L COMf	0,393	1,648
VIF L POV	0,844	6,423		VIF L POV	0,393	1,647
VIF L Led	0,845	6,443		VIF L Led	0,378	1,609
VIF L Hed	0,843	6,386		VIF L Hed	0,385	1,626

Figure 22 – Variance inflation factor (VIF) for each LOG of independent variable, where X: LOG of each independent variable and with NO outliers among independent variables
(Source: personal elaboration)

In line with the previous observations, the VIF values highlight some specific situations:

- Again, the VIF values are higher when the dependent variable refers to COVID-19 cases because, as suggested also by the diffusion theory, in that space-time process, there are actually many factors in place that influence (often together) the contagion trend. This is particularly evident when the multicollinearity-test considers "COVID-19 Cases" (and not deaths p/c) as a dependent variable, because the demographic and socio-economic factors involved are many, often linked to each other and usually more interconnected when studied in the urban dimension, as in this case;
- The VIF values for predictors are lower when considering "COVID-19 deaths per capita" as a dependent variable because, as read in the theoretical part, mortality is a more complicated phenomenon to interpret, where also political, sanitary and behavioural dynamics come into play, hence slowing down the mutual and multiple influence of the variables here considered.

But strangely and in contrast with the previous findings:

- These analyses highlight a higher value of VIF for the density feature, compared to the small correlation coefficients produced by the Pearson's and t-Student's tests and by the Correlation Matrix. In fact, while when studying the correlation between density and every single independent variable, the coefficient was usually quite limited/small (see the previous sections), on the contrary in the multicollinearity test, the VIF value for density is high (when the dependent variable: COVID-19 cases) (Figures 21 and 22). This is because while correlation refers to the linear relationship between two variables, the multicollinearity describes the strong linear relationship between three or more predictors, even though in pairs, variables have no high correlation. Within this context of analysis, a possible reason referred to high VIF values for density may be that: when coupled with other socio-economic variables, its "weight" remains limited but, when addressed with all the other predictors in the complex context of urban systems, then also the relationships between density and the other variables become high and interconnected.
- Although multicollinearity does not reduce the overall predictive power of the model, it can produce estimates of regression coefficients that are not statistically significant. In some way, it may appear as a kind of "double counting" of the independent variables in the model. Indeed, when two or more independent variables are closely related or measure almost the same thing, the underlying effect they measure is somehow considered twice (or more times) between the variables. Thus, it becomes difficult or impossible to tell which variable is really affecting the independent variable. However in the most critical case of "COVID-19 cases as a dependent variable", not only the VIF factors are not "that high" (see Belsley, 1991 and Hair et al., 1995 for the thresholds/ decision criteria), but the reason of their increase (especially in comparison with small correlation in pairs) is partly related to the complexity of the sample itself, where several demographic and socio-economic features coexist in a complex urban system.

In conclusion, another aspect to point out in this analysis refers to the value of R^2 already observed in the multiple regression analysis (Figures 11, 12, 13, 14, 15, 16, 17 and 18), in particular in those regressions (Figures 11, 12, 15 and 16) where the dependent variable refers to COVID-19 cumulative cases and the R^2 approaches 1. This condition favours high VIF values in the model, as actually observed also in these analyses.

4.4 Discussion and limitations

The poor quality of the multiple regression outcomes does not allow, in a first phase, to reach the definitive conclusion that population density or size affect or do not affect COVID-19 positivity and mortality, probably also because, as already mentioned at the very beginning of this study, the pandemic data were quite poor in quality. It can be assumed that these poorly fitting results are partly due to the heterogeneous and messy results coming from different counties but also to the different policies in place that sometimes limited the positivity tracking, the access to tests and to hospitals. Moreover, probably because many counties had a heavy increase of COVID-19 tests (also because of new job-requirements) in the recent months in parallel with the massive distribution of vaccine for the purpose of returning to work, the positivity-to-COVID data might have been seriously affected, and no longer able to report homogeneously the share of sick people. In all, these regression results might not currently be helpful for the study.

On the other hand, the observation of other independent variables suggests the introduction of other tests to investigate the possible relations between demographic and socio-economic characteristics of the sample. This analytical step has led to the observation of the close relationships between the population size factor and several other socio-economic features that influence, in turn, the COVID-19 variables (especially "COVID-19 cases"). The same strong relationship cannot be observed for the population density factor, that does not show (in the Correlation tests developed) a high correlation with the other predictors in place.

These observations allow to introduce some more general reflections, supported by literature. Moreover, the observation of some casual relationships and patterns leads to both understanding and partially predicting the evolution of the crisis event over time (Yin, 2010).

From an initial analysis of these connections and correlations, some first reflections can be made on the US metropolitan counties case study, and probably also abstracted on other levels:

_ COVID-19 diffusion at the US metropolitan county level **is not a matter of density**. Indeed, as presented also in the regression analysis and further correlation and multicollinearity tests, population density is not positively, uniquely and sharply related to higher infection rates, neither to the other predictors in place. A study led by a researcher at the Johns Hopkins Bloomberg School of Public Health (Hamidi et al., 2020) found exactly that dense areas are usually less associated with lower COVID-19 death rates. Denser counties, compared to more crowded ones, tend to have lower death rates, probably because they present higher levels of general development, including income, education, urban quality and better health care system and access. Empirical studies based on the 1918 influenza and pneumonia mortality data of the US state level and data of towns and cities in England and Wales do not provide very strong correlations between total mortality and levels of population density (Hu et al., 2013). However, international discussions are still describing dense contexts like New York as "examples of perils". A useful clarification may be provided by the concept of "household", since "population consists of households and their inter-household and intra-household dynamics" (Federgruen and Naha, 2020). In fact, the kind of domestic density and of contact rate between people sharing the same household usually is much greater than between two persons from different domestic contexts. The same was also observed in 1972 by Bartoszynski and in 1977 by Becker with reference to other epidemiological models. This issue suggests that there are various kinds of urban densities, as too little attention is paid on what urban density really means. Indeed, as Pafka (2020) states, there is often confusion between internal densities within buildings and the external densities of public life, which is shared. For the spread of Coronavirus, the most relevant density is that one related to close contact, particularly in close spaces where virus and aerosols accumulate. In this sense, McFarlane (2021) describes four measures of density, recognizing the limits and differences of each: density, as usually meant, as the number of people living in an urban area; density as those living in a house, sometimes in "overcrowding conditions"; density as gathering sites for several urban uses; and finally density referred to the "movement through space", including both the street and transport systems. Therefore, among the categories of density to be controlled and where possible reduced, there is the internal population density, much closer to the concept of crowdedness. Further steps in this direction may be addressed and developed by researchers in coming months and years, in order to prove through reliable data that crowded spaces play a more relevant role than density in explaining the spread of

COVID-19 at neighbourhood level (Almagro and Orane-Hutchinson, 2020). In this direction, the current scale is probably not the proper one to test and validate this hypothesis, as the county level is not able to map and deepen the overmentioned distinction between internal and external densities. In addition, it must recognize that over-city levels often do not perfectly represent other factors in place, including socioeconomic indicators, adherence to social distancing policies, health-care infrastructure conditions, degree of connectivity, and so on (Martins-Filho, 2021). These factors may influence population density and COVID-19 estimates with a greater role than expected.

Since most of the literature on COVID-19 and urban density develops the relationship between the "traditional" meaning of density (meant as N population/sqm) and the contagion, an interesting finding highlights that actually density has affected the timing of the outbreak in each county, with denser locations more likely to have an early outbreaks. However, longer observations did not find homogeneous evidence that population density is linked with COVID-19 cases and deaths. Carozzi et al. (2020), using data from Google, Facebook and the US Census, investigate also other possible mechanisms of contagion and show that population density can influence the timing of the outbreaks because of easier connectedness of denser location. Another interesting observation points out that density is positively associated with social distancing measures while negatively linked to the population-age and income. Thus, rather than dangerous, at higher scale density can represent a positive urban feature for increasing people sensitivity and preparedness to coexist to new pandemic requirements and praxis. In fact, as stated by Carozzi et al. (2020), both behavioural and/or policy encouraged changes in behaviour may be more effective, visible and rapid in dense counties. For instance, community compliance with social distancing measures may increase among citizens quicker than among rural inhabitants. Not only, studies on previous pandemics (e.g. the 1918 influenza pandemic) have already demonstrated that population density is not necessarily linked with the diffusion and severity of an infection (Mills, Robins and Lipsitch 2004). In addition, considering that dense counties are "younger" than sparse counties, also this element could reduce the quantity of victims in these areas. All that said, it becomes interesting to explore other potential mechanisms causing this infection spread, by looking at other possible factors behind the early beginning of the disease in denser cities. Among them, connectedness factors seem particularly interesting to explain early positive cases of COVID-19 in denser areas.

_**Commuting time** has a greater influence on the infection spread and is somehow also connected with the density issue (according to literature), but also to the population size (according to the correlation analyses here developed). Indeed, Carozzi et al. (2020) state that dense counties in the US are also more connected with other locations and this condition may influence the early beginning of COVID-19 pandemic in these areas. As previously presented, commuting patterns and, when data are available, the use of public transport offer a higher degree of human exposure and hence, to contract the disease. As stated by Hamidi et al. (2020), connectivity through commuting played a crucial role in the initial phase of infections. This emphasis on connectivity is aligned with other research combining infectious disease with the changing nature of urbanisation. Connolly et al. (2021) argued that 'extended urbanisation', including peripheral urban developments, have boosted vulnerabilities to the spread of infections. Thus, when COVID-19 pandemic was just emerging, they observed that in recent years global diseases have rapidly spread in those emerging-urbanized areas of China and Africa, comprising SARS and Ebola infections, which moved from urbanising hinterlands to cities like Hong Kong, Toronto, Freetown and Monrovia (Ali and Keil, 2008).
A personal zoom previously developed on the city of New York studies both data on commuters and percentage of public transport users provided by ZIP Atlas. Despite information actually refer to data collected before the pandemic, the outcomes pointed out the direct and positive relationship between the COVID-19 positivity and the commuting habits/public transport use. Undoubtedly, the best way to study this relationship would be to apply daily commuting patterns and use of public transport by ZIP code during the time of pandemic. To date, some first studies show that during the Spring 2020, due to restrictions and resources availability, many people changed their moving habits. For instance, the research project launched by Legeby and Koch to examine how people move during the Corona crisis in Stockholm, Gothenburg and Uppsala (Sweden) (Legeby and Koch, 2020) demonstrates that citizens were already changing their daily habits. Through survey-collection, they examine the new and temporary patterns of movement and use that occur when residents are urged to stay away from crowded places due to higher risk of being infected. An interesting finding reveals that walks are more frequent than before, as people

probably go out for specific goals and errands, and that there is a great activity near water areas. Back to the metropolitan counties perspective, it is interesting to point out the strong tie emerging from the logarithmic regression applied to COVID-19 cases, between commuting flows from the Residence County to the Workplace County (2011-2015) and the virus behaviours. Another interesting outcome comes from the Correlation Matrix and the Pearson's and t-Student's tests, as they highlight a strong correlation between commuting flows and population size, while a lower and more moderate relationship with density. This aspect may bring new reflections to light, as the fact that more people living in an urban area will probably move more (and then give less priority to working from home or travel in more sustainable ways), the increasing need to track the daily-people movements and to limit travels, especially for those working categories where working-from-home is really an option; and to regularly update data on commuters, in order to provide updated numbers. New reflections may arise also in terms of "working from home" data, that were not available for the US metropolitan county level, but that could contribute to understand the daily working habits of people. For instance, previous analysis on New York City pointed out that in those neighbourhoods, like those in Manhattan, where many citizens are employed in financial, law or other managerial jobs, working from home was already an option before the pandemic. Thus, when the emergency broke out, in many neighbourhoods the shift to this option was adopted by several high-level workers, in contrast with other categories that kept moving regularly to work daily, often through the use of public transports. In general, also for this topic, the best way to work with updated information would be to collect work-from-home data both during the time of pandemic and also after.

_**Number of persons per house** favours the virus spread. In close relationship with the first point about density, results from regression analysis highlight that the number of persons living in the same house increases their vulnerability to the virus. When making recommendations on priority groups for vaccination in December 2020, the UK's Joint Committee on Vaccination and Immunisation underlined that "occupation, household size, deficiency, and [low] access to healthcare-system" can increase people vulnerability and worsen infection outcomes, especially amongst Black, Asian and other minority ethnic groups (JCVI, 2020). While there is still at the time of writing small evidence that density in the locality intensifies the impact of the virus, there is a growing support on the idea that "crowding" in lower-income households plays a role together with other factors.

In particular, the logarithmic regression applied to COVID-19 cases, points out a strong relationship between the average household size and the virus behaviours, in contrast with the uninfluential weight covered by population density. Moreover, studies reveal that poor living conditions are statistically more relevant on COVID-19 related cases since it is more complicated for people in crowded units or communities to adopt physical distancing or to respect public health emergency protocols. Indeed, overcrowding, especially in low-quality housing and neighbourhoods, increases the risk of rapid transmission (UN-Habitat, 2020). In this case, already from early findings, density and households data suggest that crowding of shared and usually enclosed spaces plays a more central role in explaining the COVID-19 spread than the density itself (Almagro and Orane-Hutchinson, 2020). And when trying to find correlation in pairs between the housing conditions and the other independent variables, the correlation is usually very limited.

It is possible then to state that, as demonstrated also by Maroko et al. (2020), data about average household size in New York City and Chicago can be more strongly associated with COVID-19 hotspots than population density. In fact, it seems that intra-household crowding is actually a more important channel of transmission of COVID-19 than the feature of density itself. In New York for instance, the highest number of cases per capita occurred in areas with the lowest income levels and largest household sizes (Outlook, 2020; The New York Times, 2020), reflecting data demonstrating that the Bronx has 12.4% of the city's crowded households, compared with 5.4% in Manhattan (Bassett, 2020). This introduces an important topic for prevention, related to the issue of intra-household contagion and its related risks, especially for low incomes, youth and seniors. These issues may suggest to policy-makers and professionals an improvement of their capacity to provide temporary shelters to people living in overcrowded and unsafe conditions to physically distance or safely isolate, when and where needed.

_**Mean of incomes (Estimate of median household income 2019)** seems to have a negative effect on Covid-cases and deaths among the US metropolitan counties, as reported in the multiple linear regressions, as already happened in the 2009 influenza pandemic, where it represented a significant predictor (Thompson et al., 2009). These data are mainly related to the socio-economic conditions of the urban setting, and thus present different correlations with the share of positive tests. In general, what can be said is that a decrease in the median income leads to a spread of COVID-19 positivity rate. Only one aspect is worth to be mentioned comes, on the contrary, from the observation of the relationship between this independent variable and the others (in pairs or with three or more together): while the correlation between the income levels and the other predictors (in pairs) appears always weak, the relationship becomes (reasonably) more relevant when observing the linear relationship between incomes levels and the highly educated people.

In this sense, in deeper studies focused on urban distribution of COVID-19 at more local scale, most of the hot spots are usually related to those middle and low income neighbourhoods, with high rates of poverty, low quality of services, unemployment and racial disparities (Maroko et al., 2020). Therefore, within this pandemic context, it may be said that transmission-reduction policies (as social distancing) may have been more easily promoted and followed within these affluent areas than others. Additionally, integrating data suggests also that usually in those low-income neighbourhoods there is also higher probability to live in overcrowded and shared family dwellings, where the transmission of the virus among residents is favoured (Wong and Li, 2020; Truong and Asare, 2021). Thus, an impelling need that may come out from these analyses points out that income – in parallel to other spatial heterogeneities – is a great predictor of COVID-19 spread among the same administrative area.

_**Low education level and poverty** favour the virus spread, as well as its fatality. This fact has been firstly observed in the multiple regression analysis proposed. Moreover, as stated by Singu et al. (2020), among the five key determinants, called "Social Determinants of Health" (SDOH) and referred to neighbourhood and built environment health and health care, social and community context, education, and economic stability, these last two dimensions take an active role in dealing with the pandemic. Education refers to high school graduation, enrolment in higher education, language and literacy. According to the American Medical Association, the higher one's level of education, the higher her/his life expectancy is (2020). Moreover, the level of education highly influences the job type, the income, the benefits like health insurance, paid sick leave and parental leave, Thus, it becomes progressively important to also note the education level of patients, when collecting information about health in a patient-specific manner. In parallel, economic issues include factors like employment, poverty, food security, and housing stability. According to the American Medical Association (AMA), as the poverty level increases, the percentage of adults (> 25 years) with an activity-limiting chronic disease rises. Low economic levels have an impact on individual’s health in many ways, as they can be associated with depression, domestic violence, substance abuse, and physical illness. Historical reports have largely demonstrated that poverty, inequalities, and SDOH enhance the spread of infectious diseases. Clearly, inequalities in health and economic levels can further increase the disparities in morbidity and mortality. Quinn et al. (2014) stated that previous studies of influenza pandemics did not highlight the importance of health inequalities nor have they attempted to study differences in socioeconomic features and how they impact on health during a health emergency.

These evidences underline once again the need to take all these factors into account when planning and managing the well-being of a city, a county, a state or whatever. In the coming chapter, further reflections on the importance of understanding these various factors to avoid disparities in population will be developed.

_Last observation, from the current results, it is not possible to firmly make conclusions about **racial groups** and their different roles in dealing with the pandemic. They appear (logically) more related with some specific predictors however, especially to population size and density. A possible reason for the difficulty in forming conclusions on this topic is also linked to the scale used in this work. Better thinking in fact, the county level is not able to capture the role or weight of different minorities in heterogeneous communities. And in turn, within the same metropolitan county, there may coexist diverse situations and build-up settings where White, Black/African, Asian (etc) cover different roles. That said however, it is important to recognize the observations of other studies, usually developed at urban or neighbourhood level, where for instance Black/African Americans or Hispanics were more likely to live in low-housing quality conditions, less likely to be covered by health insurance compared to Whites, more likely to have more basic employments, and so on. These branches of the population who already faced barriers to the healthcare system before the pandemic, during COVID-19 emergency face a stronger barrier to primary care and related benefits.

In general, this study, despite a lack of evidence about the role covered by density and population size in dealing with the pandemic, leads finally to a **more holistic view** on the variables in place when addressing COVID-19 diffusion at US metropolitan county scale. Not only, thanks also to the observations from the multiple regression analysis, correlation and multicollinearity tests, it is possible to observe how environmental and physical elements respond to specific threats, stresses or disturbances (Allan et al., 2013) and how, in turn, they influence the stress/disturbance trend. Another interesting aspect, coming mainly from the Pearson's and t-Student's tests, the Correlation Matrix and the VIF values, is that when coupled, the independent variables sometimes show strong linear correlation while some others totally do not show relevant linear correlation, but when addressed all together, the independent variable show higher values of VIF (especially when the dependent variable corresponds with COVID-19 cases). This fact, aligned with the statistical theories, is quite interesting and reminds the interpretation to the complexity of the urban settings here analysed.

That said, from these findings it is possible to identify some "**lessons learnt**" and thus to provide some suggestions for the planning field, in terms of practical issues that professional can apply and replicate to guarantee the ability of cities to maintain stability, to recover, to adapt and to improve when answering to a pandemic crisis experience. Before moving to the last chapter and deepening these conclusions, firstly in terms of planning implications, it is important to make a passage on the limitations of this study, once that the regression-outcomes have been presented and commented on.

Understandably, the present research has also some methodological and practical limitations that should be acknowledged. Indeed, due to the decision to quantitatively analyse physical and non-physical proxies, thereby including only measurable variables, certain attributes are not included in the analysis and thus the general interpretation lacks a bit in terms of general overview. In this sense, it has to be said that some features, found in literature, were not available at the US County scale, some others were not actually adequate for this scale of case study. Few others then were not considered for lack of reliable and representative data. Yet, the lacking data can be considered in further studies or indirectly in the discussion, when some literature is at least supporting their integration.

Secondly, there is also no doubt that the assessment methodology applied has some limitations, firstly because in both kinds of regressions, two types of data are put in relationship: from one side, COVID-19 data usually follow a timeline (weekly or monthly), playing then a "dynamic role" within the analysis; while from the other side, both physical and non-physical proxies are "static", since they contain non-dynamic data, not updated (from their data-bases) along the pandemic experience. This may also lead to state that the significant features selected are not exhaustive to explain the virus spread between distinct counties. However, this work offers some initial useful reflections to read the COVID-19 spatial distribution among US metropolitan counties and, not less important, to start making reflections on the relationship between population size and density on one side and COVID-19 behaviour on the other.

Another strong limitation related to the use of multiple regression analysis refers to the weakness of some outcomes, which – sometimes differently from the linear regression analysis results, which are too partial – do not highlight strong connections between physical and non-physical proxies and COVID-19 data. Among the possible reasons, there could be a non-explicit relationship between some proxies, the limits of some more physical and static indicators to express already any changes in relation to the unexpected pandemic crisis, and the weak capacity of some proxies to represent a certain trend at the US county level. With the future ambition to improve a bit the quality of the regression analysis, the outcomes exclusion was proposed during the analysis and further tests (Perason's, t-Student's, Correlation Matrix and VIF) were developed so as to better understand the relationship between independent variables. It may be interesting to update these "static variables" when data will become available and, possibly, collect exactly those of the COVID-19 period.

Fourthly, in terms of contagion-control, it has to be said that the US, as many other contemporary countries, unfortunately did not developed a proper contact-tracing system able to find out where people got the contagion, since it is evident that some of them probably got the infection when commuting or when working in presence, or directly living in crowded contexts. This fact limited the identification of where people really got the infection and made the COVID-19 positivity simply correspond with the US metropolitan county of residency. As previously said, this lack of data can be balanced through the observation of other static features, like population size, density, housing conditions and mobility habits, but in any case, the complete understanding of contagion would have been more complete if contact-tracing had developed more.

Moreover, because this study addresses exclusively the US counties considered "metropolitan" by the CDC, there may be different trends in rural-counties, where usually population size and density are lower. This analysis may then offer other perspectives on the topic, especially on the role covered by population size and density in limiting or favouring the virus.

Finally, another limitation of this work relates to the temporal dimension that this thesis covers. In fact, the impacts of such huge events (like COVID-19) on urban contexts are usually observed along centuries, not years or few months. Although such a study would be a very interesting and precious analysis, under the current context of COVID-19 it is not possible (yet) to consider the dynamics "concluded", as they are still on-going and data collection is continuously evolving and adding information. That said, the main study outcomes – especially those addressing the two population features of interest – remain unaltered and already lead to relevant and interesting discussions.

CHAPTER 5

DISCUSSION AND CONCLUSIONS

It's really a sad tale of people who know what's coming,

but there's nothing they can do about it unless you give them housing

or get them out of this predicament.

Michael Wolf, Head of the Centre for Applied Health Research on Aging at North-western University, 30 April 2020

This chapter has its roots on the main significant outcomes of Chapter 4 but seeks to reflect also on the theoretical findings of Chapter 2, while addressing the research question with more awareness and arguments. In fact, the findings from the empirical observation of COVID-19 effects on the US metropolitan counties shed light on the county-aspects that, in dealing with a stress, may favour or limit the well-functioning of the affected counties and, more in general, achieve a certain level of resilience. In this sense, the theoretical section in Chapter 2 and the discussion of results in Chapter 4 may support the argument, while indicating which urban properties and principles are more effective in supporting the city resistance, recovery, adaptation and transformation.

Not only, there are growing reasons to state that this crisis may have served as a catalyst to rethink and reconsider some system features and related functions, but also to confirm that some elements already in place can deal also with a pandemic crisis. This important awareness needs to be developed and considered along the closing parts of this work, especially when addressing the research question and also to be proposed for further works on this topic, adopting long-time perspective and repeatable frameworks.

Following this logic, this chapter may then be structured as follows.

5.1 Addressing the research questions

When in 2015 the United Nations Member States adopted the 17 Sustainable Development Goals (SDGs), the group could not predict such a global and violent health crisis. Nonetheless, Goal 11 appears particularly appropriate to also address this issue: "Make cities and human settlements inclusive, safe, resilient and sustainable". According to the previous theoretical sections about resilience concept, it is evident then that a health resilient city is able to guarantee proper quality levels to its population, economy and environment, while favouring a permanent and sustainable growth, also in response to health crises. These proper levels should find correspondence with key spatial properties, able to deal not only with this crisis but possibly also with other critical conditions (already occurring or coming in the future). Urban health resilience requires adequate urban planning and design components. These two, before passing to the local-governance implementation, should be scientifically addressed, in order to provide key elements that should be considered when dealing with urbanised contexts in time of pandemic.

In this sense, it is important to point out that the limited/moderate weight covered by population size and density in limiting or favouring the virus at the US County level, actually points out some interesting topics for planning that should open to further reflections.

To better deepen this topic then, it is useful to address again the research questions and try to build a structured answer:

> "COVID-19 pandemic experience at the US Metropolitan County level:
> what is the role of density and population size?

Followed by these more specific questions:

a. Within this pandemic experience, are there any "propagators" or "promoters" of the phenomenon (especially after the case study analysis and in comparison with the thesis-argument)?

b. According to the data observation and results of this study, is it possible to find any urban features that may mainstream the health-criteria into the spatial planning and design field?
c. Which urban properties have been more exposed to the diffusion spatial process of COVID-19? Will the temporary transformations observed along this crisis introduce more permanent changes in the future?

The estimate of how population size and density influence the severity of COVID-19 at US metropolitan level **is hard for several reasons**.

First, as demonstrated also by the regression analysis and further tests on correlation and multicollinearity, population features are not randomly distributed and they may be correlated also with other elements of the sample, as well as indirect and unobserved confusing elements. For instance, in some areas the population densities may be the effect of local economic activities that, in turn, may influence both local economic conditions and population size and densities. Insofar as economic conditions affect COVID-19 local behaviours and demographic variables are related to most of the socio-economic ones (see the correlation and multicollinearity tests for further details), unperceivable local advantages/disadvantages and relationships can confound the effects of population size and density on the virus spread.

Secondly, differences in the observation time of the disease can lead to differences in the interpretation of both the population variables role. This has been reported by several publications on both the diffusion theory (Hägerstrand, 1967; Haggett, 2001; Haggett and Cliff, 2006) and COVID-19 urban outbreak (Almagro and Hutchinson, 2020; Carozzi et al., 2020; Wheaton and Thompson, 2020), respectively stating that (i) the diffusion of an object/event follows the idea of "wave", from an "onset" to an "extinction" phase, and that (ii) at the early stage of the pandemic, the distribution of the population density at the county level had in some cases a determinant role in the pandemic distribution. They report a relevant positive relationship between population density and the tests-positivity but, they state, "this relationship seems to decline over time" (Carozzi et al., 2020). When reflecting on the "wave" behaviour introduced by Haggett and Cliff (2006), this positive relationship may be found especially in the so-called "Onset-phase", when a new virus enters a new region where a vulnerable population is open to infection, and partly also in the "Youth-phase", when the infection rises with rapidity from its original place to more centers, favoured by particular conditions.

With time then, as stated by Wong et al. (2020), between March and May 2020, as the emergency progressed, cases-distribution became more similar to the population-density-distribution, thus indicating an increasing influence of population density on the numerosity of cases. Convincing data highlight that density influenced the time of the outbreak in every county, with dense locations more likely to observe an early outbreak. In Hamidi et al. (2020), the most important finding of their study, based on finding the impact of density on COVID-19 contagion and mortality rates for 913 US metropolitan counties, is that density is not related to confirmed virus rates and inversely related to confirmed virus death rates, also extending the control for other variables. They basically did not find a significant relationship between density and COVID-19 infection and mortality rates. Indeed, when considering the number of deaths per capita, density appears to be poorly associated to COVID-19 mortality. Thus, it is mainly a general assumption that high-density levels are related to higher rates of transmission, infection and mortality (Hamidi et al., 2020). The same can be found in Boterman (2020), who did not observe relevant positive relationships between county density and infection rate in the Netherlands, which is usually densely populated and highly urbanized. Also in Lin et al. (2020), in China the linear relationship between population density and the COVID-19 spread rate disappeared progressively. In Carozzi et al. (2020), when adjusting the timing of the disease-beginning in every county, the evidence of population density impacts on COVID-19 incidence seems to decrease. This trend suggests that since the virus spreads via human contact, denser areas offer more opportunities for interactions. Nevertheless (*questions "a" – "c"*), by time, several influencing factors enter into play, affecting the behavioural reaction to the pandemic. This aspect has been addressed in this analysis also through the multiple linear regression and the correlation and multicollinearity tests, that pointed out the role covered by other independent variables of the sample, as the commuting flows and the education levels. These features are responsible for favouring the spatial distribution of the virus, on one side, and for giving a certain cultural and social framework for the pandemic diffusion, on the other.

Third, data reporting COVID-19 cases may be considered with partial reliability, because of errors in local testing capacity and strategy. Indeed, there is undoubtedly a percentage of asymptomatic persons that makes the recording-process of infected people quite difficult (Subbaraman, 2020). The same can be noticed for the number of COVID-19 victims, which is referred to deaths in hospitals and thus, excludes deaths at home.

Therefore, from these reflections and previous regression findings, it can be said that high density levels do not provoke faster COVID-19 spread in the US metropolitan counties, beyond the early onset of the infection observed by literature and other studies. In this process, there is no doubt about the greater opportunities offered by denser areas to human interaction, but it is also clear that other mediating factors concur in this mechanism. For this reason (*question "b"*), it is possible to assume that density – partly together with high levels of population – may then represent a crucial urban characteristic to mainstream the health criteria into the spatial planning and design field. This is because of the potential socio-economic conditions that may benefit from it, as well as the evident condition of multicollinearity that already exists between density (the same happens for population size) and the other independent variables of the sample. Therefore, planning disciplines could identify in "population density" an urban feature so resilient that it can adapt to the novelties introduced by the pandemic, transforming some of its functions and integrating new health-criteria within.

The situation is a bit different when considering population size, whose role can also be associated with the scale applied in the study. For instance, when working at Country level, Lulbadda et al. (2021) pointed out that the virus spread can be increased with the growing number of people. The same has been observed in this analysis, where in different regressions and tests, usually population size seems to influence the sample and favour the vulnerability of some variables to the contagion. Thus, it is fundamental to also consider the population size of a certain area when studying the transmission of COVID-19 and, again (*question "b"*), reflect on the possibility to mainstream through it the health criteria and consequent socio-economic benefits. To reach that, logically, much depends also on the internal context of each county. For instance, in those heterogeneous cities like New York where, in its different counties/boroughs, very distant socio-economic communities coexist, the presence of vulnerable population subgroups may have different roles in dealing with the virus. These specificities cannot be perceived by the pure population size number but, starting from this data, then also other variables in place may be improved and mainstreamed. Multiple regression analyses above suggested in fact the presence of these internal connections, then proved by the correlation and multicollinearity analyses, by limiting the positive influence of population size on COVID-19 cases and deaths (in fact, this line never appears "statistically significant").

All these reflections introduce then the need to integrate these findings in planning disciplines, with proper strategies and policies.

A possible innovative step may come from the introduction of more permanent changes in the future of our urban contexts, starting from the temporary transformations observed along this crisis (*question "c"*). Among them, a recurrent topic has to do with the work-from-home habit instead of the daily travels that increase commuting flows (and as a consequence, the virus diffusion). This growing habit, whose data should be updated and then published for being integrated in further studies, may actually represent a permanent condition for many workers in the future. And considering the concentration of job-buildings in urban areas, this crucial shift in the work-practice may also provoke relevant changes in the use, functions and forms of some areas. In a new context like this one, moreover, it is clear that a new pandemic may impact less, or at least, slower and according to different dynamics in place.

In general, comprehensively, recent findings by Chu et al. (2021) indicate that prevention, dynamics and control of COVID-19 are not directly linked to the size of the city, but rather to proper governance capacity and application. Their analysis, based on 276 prefecture-level Chinese cities, highlights that along the prevention and control phases of the COVID-19 pandemic, urban governance capacity represents a crucial factor. Moreover, their results allow to assess the mechanisms by which urban strategies and policies have some influences on prevention and control, providing new awareness and knowledge that can be used by politicians, stakeholders and representatives to develop better-informed public crisis prevention and control systems. These aspects will be discussed in the next section.

5.2 Role of space and scale

As said before, turning the attention exclusively on levels of population density and size in single counties is not enough. In fact, the concentrations of population and the virus-spread are not bounded or controllable by administrative or statistical units, and this helps to understand why the county-scale is not always the proper one. From a methodological point of view indeed, the regression models proposed explored the relationship between cumulative cases (also their log) and population density or size (or their logs), understanding if high population size or density are related to more cases. Therefore, the two population variables reflect the situation of the population over an area – in this case a metropolitan county – thus how closely persons are "packed together". But these boundaries are often the outcome of historical local developments with little updated reference to the real population distribution. Some counties are actually cities with a small area but high population densities. In other cases, some major cities like New York or Washington D.C. are internally divided by several counties, each is in a limited area but with high population size. For instance, the four New York counties of Manhattan, Queens, Kings and Bronx present high densities but actually they are different not only as separated administrative entities but also in terms of socio-economic conditions. Moreover, the population size itself can seem large or small, depending on how large the counties-footprints are. From a mathematical point of view, this means that the regression models may present more cumulative cases for high density counties with relatively small-moderate population size, than the real population size of these counties.

In addition, since population density reports the situation of the population (as the four New York counties), the model theoretically reflects that high density environments are associated with high levels of cumulative COVID-19 cases over an area, unfortunately not reporting any specific locations within an area, a county or a region. This means that the interpretation of a feature, a dynamic or a relationship at the county level sometimes is "moderated" because the scale and the outcome are "indicative" of a broader situation, rather than focused on certain anomalies. Therefore, the regression models sometimes can account for pandemic situation in counties where the population density may not seem high but the population density in some neighbourhoods may be. In addition to that, the diffusion "wave" may follow then unexpected speeds or behaviours in some places and, in parallel, several other socio-economic variables may be interconnected internally.

Population size and, more than all, population density may vary considerably within the same county, specifically in those counties close to metropolitan areas, where both urban and rural land uses coexist, thus creating inevitable spatial concentrations of people. The regression models in this work cannot offer proper R^2 values also because of this failure of the county level data in capturing intra-county variations. Thus, it is reasonable to point out that when data are available, higher spatial resolution would be preferred as it is finally clear that COVID-19 involves also socio-economic and spatial dynamics and sub-county scale (Lam and Quattrochi, 1992). Indeed, as argued before, population density levels may vary considerably within a county, despite its high multi-correlation with the other predictors in place. Adopting the county level population size and density allows to make comparisons (more than among cities, whose uniform data are missing in the US), but fails to consider the local situations or anomalies. Hence, when data are available at community – neighbourhood – census block – ZIP code levels (in more cities, to make the outputs comparable), the observation of population density can support the understanding of disease transmission. This perspective can also be applied for the population-concentration, since subgroups of people are usually detectable at the sub-county level. County data collected by CDC and used in this context are too gross to capture high densities and people concentrations and their weight at sub-county scale.

Therefore, an important lesson learnt from this study is that, once understood their potential and important role in dealing with COVID-19, future studies and databases should provide homogeneous and updated data at the sub-county level to allow researchers and politicians to investigate and detect these topics at the right scale.

5.3 Implications in Planning Theory

Although the regression models observing the several variables have just partly demonstrated the role of the two population features, in this section they key-findings of the research are integrated in a broader perspective of planning, where also the theoretical concepts of Chapter 2 are addressed again. Therefore, with reference to the diffusion theory, the adaptive cycle, and the resilience perspective presented along the work and the analysis of the case study, it is possible to make some considerations.

The impact of this pandemic on urban systems highlights the need to pay attention to urban dynamics over time and across scales, also considering the distinct but interconnected steps of the diffusion theory introduced by Hägerstrand (1967) and Haggett (2001) and of the resilient adaptive-cycle introduced by Holling and Gunderson (2002).

In this sense, four distinct phases have been recognized, according to literature (Holling and Gunderson, 2002): “Exploitation” (r phase) and “Conservation” (k phase), “Release” (Ω phase) and “Reorganization” (α phase), which may integrate the steps of the “wave” process followed by the virus diffusion. Since the focus here has been put on the crisis experience of COVID-19, the Exploitation and the Conservation steps are not directly addressed but simply meant as a sort of “state of the art” that led US metropolitan counties to a certain pre-pandemic stability which is also more rigid and less capable to innovate. The “Onset” and “Youth-phase” of the virus-diffusion (Haggett and Cliff, 2006) probably found fertile ground within these conditions, favouring the early and more local diffusion of the infection. According to theories, in this phase, resilience is low and any stressors can potentially provoke the system collapse.

In fact, when the focus of this work turns on the COVID-19 outbreak, the urban system surpasses a certain threshold and experiences a sudden collapse, represented in this case by a rapid spread of contagion and deaths according to different severities and because of different spatial and socio-economic conditions, together with a horizontal unpreparedness. This phase may also correspond, in terms of diffusion theory (Haggett and Cliff, 2006), with the so-called “Maturity-phase”, where the diffusion-intensity is highest. Thus, through the “Release” (Ω phase), the crisis pushes the system to re-understand itself, underlining new needs, finding new solutions and introducing new creativity and energy as a potential for renewal. This step can be considered, within the current thesis-context, the most interesting adaptive-cycle stage, as it has prompted many urban contexts apparently in equilibrium to observe with a critical point of view several urban aspects, and to re-evaluate certain traits, habits and functions.

Later, in the "Reorganization" (α phase) which is starting cautiously, new awareness, priorities, knowledge and availability of capital, energy, resources and information can logically support new forms of organization and management. This is also possible as in this phase, there is reason to consider the diffusion behaviour in a "Decay" and progressively "Extinction-phase", where it is going to descend and report fewer and fewer cases. Understandably, reorganisation can assume many forms in the current counties context: from a repetition of the previous cycle, to a totally new regime characterised by different processes and structures, thus assuming an unpredictable trajectory or a new trajectory full of lessons learnt from the crisis experience. Nonetheless, as previously mentioned, some elements will probably change, albeit the process will take a long time. In any case, what is important to understand after the observation of this crisis at the US metropolitan county level is that, first of all, resilience-perspective can support the whole process and planning structure (possibly starting a new cycle); and that, secondly, the long-time perspective is what can sustain a continuous balance of the system.

In this sense, a good approach for planning is that of understanding the urban system as part of an ongoing process, in which several elements can be integrated. These elements, presented above, can potentially enhance the urban system resilience in a way that may offer guidance to future planning practice. They open the view on broad concepts, typical of the complex system understanding and evolutionary resilience literature.

- **Change**: Change is one of the fundamental elements in evolutionary resilience discipline since it allows the understanding of complex systems and of change-dynamics over time. When addressing change, also referred to as "transformation" in the urban system, two concepts become particularly central to understand the role of change in evolutionary resilience enhancement: the adaptive cycle and the Panarchy model (Gunderson and Holling, 2002). While the first one favours the understanding of forces facing periods of gradual and rapid changes, the second one addresses the hierarchy of complex systems and the relationships of adaptive cycles across different spatial and temporal scales. The COVID-19 experience points out several changes needed in many global sectors in order to move to a trajectory of sustainable human well-being (Walker et al., 2020). Transformability, meant as the capacity to undertake transformation, introduces three approaches:

I. Accepting the element of change as necessary, as something that sometimes occurs rapidly as a result of a crisis;

II. Opening to the alpha phase through experimentation and search for new options;

III. In the growth phase, collecting the useful structures, processes and support (from policies, finance, politicians, local representatives, etc.) to improve them.

This experience of change introduced by COVID-19 and its diffusion behaviour point out the natural alteration between periods of stagnation and picks of crisis (and related transformation) making then resilience theory a proper framework to address these new needs, questions, and perspectives. Both approaches in this sense, can actually represent a lens through which reading, understanding and addressing the current pressing concerns. However, when referring to the adaptive cycle model, it is also evident that the so-called "critical threshold" (that leads to a sort of collapse) has already passed with the peak[17] of infections, victims and hospital admission and thanks also to the early vaccination process, the urban system is now experiencing the Reorganization α phase, where new forms of organization are driven by new energy, invention and experimentation attitudes. But this reorganization can assume several forms: from a repetition of the previous state-cycle developed by a sort of new trajectory to a totally new condition characterised by new forms, functions and processes.

This condition, characterising each adaptive cycle of a city (in this case, it may be referred to the ZIP Code structure), has to be integrated with the more complete view of Panarchy, as this model introduced by Gunderson and Holling (200) puts the stress on the fact that not all such cycles take place at the same spatial and temporal scale. This link is useful to state that some changes introduced by COVID-19 at local level, especially those linked to the features included in the analysis, may extend over large areas with wide transformation processes,

[17] During the first wave of COVID-19, between February 29–June 1, 2020, the peak was reached in terms of both cases and, later, deaths, favoured also by a general unpreparedness that favoured chaos and disorder.

while others may simply take place in small zones over specific temporal lengths. This perspective opens to a new scenario where structures, functions and processes at small scale level potentially decide to address the most critical issues that favoured the spread of the Coronavirus, leading then to spatial changes as: an improvement of compacted areas, to improve the life-quality standards of denser sites; an introduction of work-from-home policies, an offer-increase in terms of households, to improve the standard-living quality, an improvement of the mobility options, as more PT lines, new biking networks, to favour the citizens passage to less crowded and more sustainable mobility offer, and so forth.

Nonetheless, these small changes introduced at a more local level will not remain isolated from each other: small changes introduced at process and small level tend to nest with larger scales and periods. Thus, if a new model would be able to collect information on the US bigger cities, supported then by their metropolitan counties, then it would result easier to make reflections and take decisions also at bigger levels. In fact, in Panarchy models, the process of change occurs both from the top-down and from the bottom-up levels at the same time, despite the two do not work in the same way and at the same speed.

- **Diversity in agents, actions and functions**: In complex socio-ecological systems facing a crisis phenomenon, diversity is also meant as the co-existence of groups of agents and actions with specific functions, which turn to be useful for the system-performance (and related understanding). Indeed, the variety of agents, actors and functions creates a diversified urban system, able to increase the potential interactions, innovation and creativity at different scales (Salat et al., 2014), as well as the vulnerability levels. This variety, under the current context of analysis, can be supported by both physical and socio-economic components that basically guarantees the adaptation or evolution of a function when a crisis breaks out. Moreover, if each function is sustained by more than one species, then the ability to absorb shocks is higher as the function can still count on agents, actors and actions left. However, when lacking a certain diversity in terms of functions and dynamics in place, then also agents and actions tend to get stuck and somehow slow down the process of crisis-response. Commonly, a comprehensive urban management plan should totally invest in basic health services at an early stage and coordinate several departments, interests, and stakeholders in reaction to urban pandemics in a timely and efficient manner (Duggal, 2020; Shammi et al., 2020; Thoi, 2020).

Thus, this kind of diversity, according to Suarez et al., 2016, is named “response diversity” and is able to increase system-resilience. To Salat et al. (2014), the presence of this framework in urban ecosystems, together with people, movements, business, institutions, built-environment and socio-economic diversities can be crucial to sustain urban resilience.

- **Self-organization:** This property introduces the capacity for urban systems to self-organize during and especially after a stress/shock. This characteristic, in line with the concept of change, should drive toward a process of permanent and restless adaptation, characterised by strong invention and experimentation. Also in terms of psychological resources, in a pandemic situation the self-organisation of life under changing and stressful conditions becomes a crucial issue to address. This perspective, in addition to both urban and personal dimensions, dismisses the idea of the existence of a permanent equilibrium state and recognizes, on the contrary, the presence of the element of change. This presence inevitably leads the system components to self-organize, while keeping on evolution and adaptation processes along an open-ended path (Gunderson and Holling, 2001). However, in the current case study, it is probably too far to hope that at the metropolitan county level a clear self-organization capacity can be achieved. First, because the administrative scale of county – as stated above – is not uniformly organized nor experiencing the same stress; second, because as stated also by Gunderson and Holling (Gunderson and Holling, 2002), the virus is still circulating with different impacts and speeds, thus limiting also the early self-organizing attempts of the adaptive renewal cycle.

Nonetheless, what more clearly comes out from early references and newspapers, is a general capacity – developed by several US metropolitan county systems as a whole – to somehow absorb the pandemic disturbance and slowly start reorganizing while experiencing change, so as to still retain the same structure, functions and feedbacks (Walker et al., 2014). A new awareness may turn the lights on flexibility, planning goals, persistence, modelling conditions and uncertainty acceptance. In general, from Walker et al. perspective (2014), it can be stated that complex systems are constantly subject of several internal or external pressures and while experiencing them, they constantly evolve and organize to new conditions, which may be partly or totally different from the original ones. Self-organization capacity will be a necessary element in this process and will support evolutionary resilience also in the future.

In this scenario, the role of population features as size and density may not explicitly change but at the same time, it may experience tiny and gradual adaptation through their basic presence, associated to internal processes of self-organization, better guided and supported by proper planning and governance frameworks.

- **Knowledge/learning capacity:** This property is strongly related, especially at process-level, with the element of change. The reason mainly links to the adaptation concept already mentioned: the mutual learning from past crisis experiences can favour experimentation and creativity at practical level. More specifically, in terms of spatial configuration, some features and functions may favour the processes of mutual learning from past crisis experiences and then apply adaptive capacity and successful innovation. In fact, along the re-organization phase, there is a need to combine the “top-down remember influence” to return as much as possible to the condition pre-crisis, and the “bottom-up activity” in collection renewal and innovation (Walker et al. 2020).

In this context, the COVID-19 experience within different US metropolitan counties points out several limits of the current structures and functioning, therefore increasing the awareness and knowledge on the most critical issues that favour the virus-spread. Folke (2006) underlines that in similar crisis-events, learning from past experiences and from internal limitations can improve not only the adaptability and transformability of systems, but also the range of opportunities for starting new things, mainly observed and experienced directly in the new crisis experience. And in fact, this pandemic, as already happened in the past with previous pandemics, underlines new needs for the urbanized contexts and their communities, linked for instance to the pros and cons of living in denser areas, to the advantages of shifting to working-from-home options, of re-designing internal spaces (both at home and in offices), of reducing socio-economic and cultural gaps, of having easier and closer access to basic services, and so on. This awareness may guide new political, planning and socio-economic processes of transformation in urban environments, working at different spatial and temporal levels.

5.4 Implications in Planning Practice

Since the beginning of the COVID-19 crisis, the academic and scientific community has focused on the understanding and assessment of the virus, its physical and socio-economic impacts, possible adaptation policies and plans. The ambition is to develop a pandemic-resilient urban planning practice in order to "manage" the virus and its impacts along the whole pandemic process. This effort requires the redefinition of unsustainable urban conditions, overcrowding situations, mobility patterns and social inequalities. In this sense, increasing studies found that the role of the urban built environment in the dimension of health and well-being turned to differ considerably between the COVID-19 period and the pre-COVID-19 time.

In this research, the focus is primarily turned on the role of two population features, population size and density, in the COVID-19 diffusion and then on how their integrated understanding can implement planning field. An important finding in this direction was that their effect on COVID-19 diffusion was non-significant, especially in terms of density. At least, not significant as other important factors belonging to the socio-economic dimension and affecting more directly the prevention and control of the virus. When the COVID-19 pandemic arrived, with a lot of fears and unpreparedness, most developed counties and cities were put in a lockdown condition. In this context, a rapid equation began to circulate, linking urban spread and the virus spread. New York sample of high cases and deaths numbers was quickly related to its high urban density. New talks started rise about the future of urbanized areas and large cities, with the idea that the Era of cities has come to an end and thus, new forms of built-settlements would rise in the post-Covid context. However then, as time passed, infection distribution and rise within different countries and more local-levels started to report geographical differences: previous urbanized contexts around the world began to reverse the trend, reporting lower rates of infection and fatalities, and leading analysists to look again to their data and findings. In this attempt, it became clear that blaming urban density for COVID-19 diffusion is a superficial over-simplification. Rather, as demonstrated by a lot of literature and also by the outcomes of this work, what emerged was a heterogeneous range of factors involved, the possibility for both density and population size to cover different natures according to the context, and the distribution of services, mobility patterns and economies. In this new scenario of observations, it became also clear that other major changes were accelerated by pandemic, projecting themselves into new needs and functions, as remote working, distant teaching/learning, e-shopping- e-meeting, etc (Mouratidis and Yiannakou, 2022). For all these reasons, this stressful experience is expected to bring its own effects also on how denser urban spaces are seen and how their life-quality will be planned and designed in the future.

Moreover, and this aspect should be highly considered in terms of policies and planning practice, when mentioning density, according to Florida (2020), a distinction should be made between "rich dense places" and "poor dense places". In the first case, people can shelter in place, work from home, have food or other needs delivered at home; while in the second one, people are pushed out into streets, public transports, and stores in order to get what they cannot have at home. Thus, in those places where people live in multi-ethnic and generational households, work by presence, use regularly public transport, the count of cases has been higher. The sum of all these factors highlights a remarkable marginalisation and a heterogeneous socio-economic condition that, more or less everywhere, led to more cases in poorer parts of the urbanised contexts than in wealthier counterparts (particularly true, as also mentioned above, for New York for instance).

Possible strategies to flat the curve in denser realities then refer to:

- start proper and already present protocols,
- introduce early lockdowns,
- allow employees to work remotely,
- allow the shelter in place practice in safety,
- improve the access to testing and screening,
- introduce tracking and tracing.

The combination of these strategies can play a relevant role in those contexts characterized by high density levels and can somehow offer also a more rapid start of resolution.

Thus, is density itself part of the solution?

Even though the pandemic is still undergoing, there is reason to state that dense areas can actually be part of the solution to the current pandemic and future pandemics. Echoing T. Jefferson quote about pandemics and cities in 1800 (just at the very beginning of this work[18]), more evidently than in the past, today the presence of many people in dense areas represents an opportunity to foster innovation, create jobs, welcome diversity, learn, let culture blossom, etc. However, concerns on density should not be confused with the critical issue of overcrowding. Despite their inequalities, denser places provide creativity, diversity and tolerance which, in practical terms, when dealing with pandemic crisis may translate with easier access to healthcare and basic services, more rapid circulation of information and self-protection measures, wide alternative of mobility solutions, and easier behavioural - emulation practice.

Moreover, as partly read when addressing the research question "b", dense urban environments can also represent crucial assets to fight pandemic disasters like COVID-19, as denser urbanised areas see a concentration of resources, business activities and social services. In well-resourced contexts, thanks to the mainstream of health-criteria into the planning issues, people have an easier and quicker access to hospitals and health care, to the "social infrastructure" and to multiple public transit, all in precautious ways that can both mitigate the pandemic effects, and adapt to them. The topic of adaptation will take with no doubt a prior role in the post-Covid phase, also in face of another crisis already occurring everywhere: climate change. The need to introduce extensive, growing, and competent discussion about the element of change and ways to deal with it becomes then fundamental, especially in those well-structured and overlayered contexts as cities. In this sense, it is reasonable to imagine the presence of public health experts to the urban planning and design tables, so as to offer a renovated perspective on those urban features that can promote physical and psychological well-being. The solution then is not purely density, but density done properly.

In this scenario, density is already a big actor when dealing with this big threat, since it contributes to the advantages of agglomeration, while contributing to the economic-power

[18] "*The yellow fever will discourage the growth of great cities in our nation; and I view great cities as pestilential to the morals, the health and the liberties of man*".

houses of most developed countries, with high-infrastructures in support. Also in terms of poor households, density may offer the support to survive, also addressing the most dangerous environmental threats already occurring.

Therefore, more efforts are required to offer dynamic spatio-temporal measures of population density and across several scales, from the agglomeration to the building level. This information could support the application of actions and restrictions in the most appropriate places (Chang et al., 2020). In all cases, what literature and analysis-results suggest is a need for more research on factors-interaction, different urban scales, and adaptation measures. This will require both more quantitative and qualitative research: from the quantitative point of view, more updated and inter-scales data are needed, so as to monitor any density changes that may occur, especially under pressure. From the qualitative point of view, more research can help the understanding of the variables-interaction over time (Gupte & Mitlin, 2020). Therefore, density can favour the understanding also of other urban living conditions as liveability, activity, environmental quality, health benefits, and so on.

The relation between population size/density and health issues should be framed in a vulnerability scenario, integrating the variables of exposure, sensitivity and adaptive capacities of each context. COVID-19 represents an unprecedented experimentation in contemporary time, to both advance:

- rapid answers that could represent a "**transformational adaptation**" for urban systems, as the transformation of (some) land uses and places, the relocation of some systems, the shift of some functions, the reorganization of well-structured or obsolete systems, the use of tracing applications, and the isolation of the so-called "relational density", and so on;

- **long-time perspective strategies** that will not necessarily lead to changes in the way population size and density are concentrated in urbanized areas, but rather in how they are managed and integrated with other factors. According to Acuto (2020) and Keenan (2020), those contexts that will be able to best learn and capitalise not only *from* but also *while in* this crisis experience will be better prepared for future health crises.

In conclusion then, it is reasonable to state that what seems to count is how density is designed and applied, which is in turn related and integrated with other functional dynamics.

Good urban contexts are those that intertwine all the elements together (from people, activities, institutions, and knowledge capital, to regulations, spaces, infrastructures, buildings, gardens, and so on). Some possible ways to move in that direction, having observed the current analysis outcomes, include:

- Favouring a **more comparable density**: better reflecting on the case study and literature, density levels are usually comparable in quantitative terms, but are starkly different in qualitative ones. This means that the kind of density and the way density "is done" need to be deepened and integrated so that all residents and users can benefit. The same may happen with reference to the study context: while a lot has been said and published at the urban/metropolitan level, not the same can be observed and read today for the rural contexts. However, as previously noticed, at that level the quality of density changes and, together with other relational and dynamic factors, covers a different role in COVID-19 diffusion.

- Intensifying the **use of the outdoor spaces**: among the lessons learnt from this experience, there is a growing awareness about the beneficial effects of staying outdoors (and in case of a pandemic emergency, reducing then the possibility to get infected). However, excluding those areas on the Planet where winters can be harsh, those places that benefit from relatively benign climate can really take into consideration the possibility to conduct more of their daily life outside. These initiatives, not only support low-energy uses, better mobility habits and expansion of outdoor tradition among workers, but favour also ongoing efforts to integrate the topic of nature in cities, while promoting a more equal, accessible and homogeneous distribution of these spaces in the metropolitan area.

- **Diversifying mobility**: since commuting remains a critical spot for COVID-19 circulation, especially in denser urbanized areas around the world, the progressive introduction of autonomous mobility offers more sustainable vehicles and integrated mobility networks, which open new opportunities to shift the mobility paradigm. Moreover, a more integrated and competitive system could increase the offer for commuters and could also lead to greater flexibility of job chabits and schedules.

- Introducing in the design field the topic of “**cyber-physical city**”: considering the increasing regular of Zoom, Meet, Skype video calls and so on in this crisis period, there is reason to think about integrated communication and sensor systems that outline a mixed “cyber-physical” city. Planning the cyber-physical city presents however huge challenges, such as in managing and ensuring data privacy, protecting from cyber-attacks, and managing the stresses coming from the mix of domestic and professional activities in compact buildings. To realize that, new flexible work designs will be required along with greater integration of virtual technologies.

In conclusion, many benefits of urban density were already known and through this crisis, new ones have arisen. However, the topic of density alone is not enough. It has to be woven into the planning dialogues and practices, so that all its advantages are harnessed for all in the post-COVID-19 world.

5.5 Lessons learnt from the case study and final bullet points

Despite the COVID-19 pandemic can be seen as a world-devastating event whose long-term consequences can just be supposed today, there are several early assumptions that may be deduced from this experience. Indeed, several phenomena and reactions observed just reflect the dynamics that were already in place before the outbreak, underlining structural issues related to the planning, political, professional and community fields. Many grounds were already under stress before the pandemic and this crisis has simply exacerbated critical situations that remained unaddressed for a long time. The issue of density and population size is one of the topics on the ground, already "under observation" before the start of the pandemic and "marker" of consequent inequalities and different stressor-reactions.

Thus, this COVID-19 pandemic has led to new crisis-level topics adding to the built-environment "quantities", quality and obsolescence issues, those of urban inequalities, lack of access to healthcare services, green areas and commerce, mobility patterns and network, equal job opportunities and much more. According to the Edelman Trust Barometer 2020, provided before the pandemic, most of people worldwide are afraid of the feature and doubt the government's ability to respond effectively to changes. Thus, the future of our urban contexts is also based on the capacity to re-think and re-plan our cities, re-build trust in institutions and bring communities closer to important issues, such as health in urban society. According to Sharifi and Khavarian-Garmsir (2020), the major lessons collected studying the impacts of COVID-19 on cities are mainly related to four major topics, such as: (1) environmental quality, (2) socio-economic impacts, (3) management and governance, and (4) transportation and urban design. While they refer to different working-agenda, they are particularly interlinked and potentially addressable simultaneously and synergically. And in this specific thesis framework, reflections on density lead to understand that density itself is not to blame. Denser cities and urban regions are so rich in activities, contacts, proactivity and interactions that they will not disappear after this crisis-experience. On the contrary, this property may be strengthened, turning finally the attention on proposing "good density" rather than expansion or diffusion.

However, the COVID-19 pandemic has emphasised the fact that, despite what literature suggests, several urbanized contexts, are still far from the idea that the crisis condition may become central in their future, following every time different behaviours, and thus resilient perspective may cover a crucial role to success. Specifically, the US metropolitan counties represent the core of an urban nation in a connected urban world, whose internal and interconnected dynamics in place influenced a lot the COVID-19 diffusion. Urbanization will probably accelerate when this crisis will pass, and it is necessary to consider the predominance of built-up contexts in future strategies to address major urban challenges worldwide. In this sense, it is important to learn some first lessons from this experience and keep them as first contributions on the early research on the topic of COVID-19 pandemic crisis.

_First of all, despite the recent attempts to link density with the spread of the virus and re-discuss old stereotypes about urban life, the idea of rethinking urban density is a senseless argument. **Planned and layered cities**, like most of the American cities and also most European ones, **remain our best expectation for survival and civilization representation**. If COVID-19 has illustrated anything, it is rather that contemporary and metropolitan mobility and global connectivity have emphasised how interlinked humanity is wherever you live. This happens at any scale, including urban and more local neighbourhood scales. This dynamic is valid worldwide. Moreover, most of the world's population already lives in urban areas and by 2050, the urban dwellers will expand to over six billion. Thus, density alone does not represent a key-risk factor contributing to the virus-spread (Sharifi and Khavarian-Garmsir, 2020). Rather, the attention should progressively move on the quality of density and the relational levels exchanged in denser contexts, with the consequences on the virus diffusion. This increasing awareness highlights that cities are at the heart of the solutions to every most pressing issues. Therefore, the acceptance of the urban density and high population size is a matter of realism and preparation and, with this in mind, the adaptation to our future planning measures and approaches becomes crucial a crucial step to move forward with pragmatic solutions that try to strengthen and improve it, not to reduce or interrupt it.

_ Secondly, the COVID-19 emergency underlined that the **consolidated and conventional approach to city-planning and building is often inadequate** to meet recent and future challenges. The pandemic crisis has sometimes forced local leaders and communities to make serious modifications in place and not always in coordination with the urban planning department or urban planning strategies. Moreover, despite the ambition to invest more in the system and inter-professional collaboration over the last decades, to date cities have been very often designed and planned with single topic-perspectives that turn to crucial fields as land use, housing, public and open spaces and mobility in a too independent way, with specialized professionals applied solely in that topic. Some urbanised contexts directly lack adequate levels of green areas and open spaces to meet outdoor activities and demands. The effects of this approach are evident in many developed contexts, as also demonstrated by the regression outcomes.

Therefore, it is crucial to consider the lessons learned from this experience so as to plan accordingly and mainstream more disciplines in planning for the better in the future. A desperate need for more integrated approach to planning is needed, where different disciplines and professionals interact and work together. According to the Rockefeller Foundation, the efforts to bring resilience to the centre of city-building through proper measures, strategies and investments should lead to the creation of a long-term process and technical assistance to enhance resilience from higher to the local level. Overcoming these unexpected crises and new perspectives can also enhance resilience to other relevant threats as climate change impacts which are in turn already highlighting urban inadequacies, vulnerabilities and lacks. Moreover, the Foundation also underlines the failure of its major commitment in several contexts after several years, partly because there were no deep and transformational results. The main reason for why this did not happen can be found in the fact that the declared efforts to build resilience did not fundamentally change the way cities are planned, designed and built, but they simply work on resilience within the context of impoverished and obsolete city-building structures. Thus, there is a need for more integrated and differentiated planning at local level and political, professional and scientific support to accelerate this transition.

_ A third point refers to the lack of public engagement in some areas and about some issues, with an evident and consequent **deficiency of public engagement in some urban topics**. Despite urban density and dynamism supported the rapid circulation of information about the COVID-19 outbreak, the public awareness, the access to health services and to open spaces, and the mobility patterns were too much fragmented and could not guarantee the same level of access in each US metropolitan county and within them. Thus, especially during the first COVID-19 wave (from March to April/May 2020), a general confusion, fragmentation, fear and poor public participation in the collective effort prevailed. This experience underlined that public presence, efforts and participation need then to be planned and grown with constancy, strategy and long-time perspective, especially in those counties where a city prevails but actually also the closer communities take a role. Such an approach may guide urbanised contexts facing also other big issues from pandemics, such as climate change, housing, transport revolution, and so on.

In the current case study for instance, the difficulty held by some US metropolitan counties in limiting contagions underlines the need to cooperate with local communities and representatives, since local governments can legally take land use decisions and point out local inequalities not represented at the general county scale. Overcoming such inequalities should become a priority for cities recovering from the pandemic and facing also other emergencies, like climate change. Moreover, by far local government still represents the most trusted level of government and is considered as the easiest accessible level of government to favour community participation.

_ A fourth aspect refers to the **need to integrate within the built-environments some changing-inputs derived from this pandemic experience**. Thus, as past pandemic experiences led to redesign and replan cities through the management of water and waste, in this context a huge lesson learnt refers to the way we live and manage our movements in urbanised, dense, and (not always) highly connected space. In this sense, considering the wider context of climate change and sustainability, what should change in terms of population distribution, urban forms and function refers to an equal decentralization of services in more agglomerated and compact nucleus where density keeps its centrality in a more effective way, better management of supplies and food delivery, a homogeneous distribution of green areas, an increased and heterogeneous mobility offer and, very revolutionary, a proper digital response to this and other kinds of emergency. This innovation roadmap highlights the need to make the whole complex **urban system decentralized**, in a way that can secure the future without interrupting the current trends and business. In this decentralized context, the digital infrastructure represents indeed a key driver for any decision people will take, and when experiencing a pandemic, it will be able to support major services for preventing and giving care. Thus, if modern planning is born in the mid-19th century through the sanitation development to face the spread of malaria and cholera in cities, the development of decentralised-dense centralities and digital infrastructure may guide the "recovery" from COVID-19, while maintaining continuity with cultures and well-established societies.

_ A final and fifth lesson learnt has to do with the role that resilience can cover in this scenario, possibly **being a proactive property and not just reactive**. This means that when an unpredictable and heavy crisis like COVID-19 bursts out, then urban system response is not just organized around rescue-work for the crisis event, but rather begins with a broader and deeper understanding of the urban system, interlinkages, functions and operations. Such an approach allows urban complex systems to learn from past experiences and proactively find new strategies to reduce the impacts of future unexpected events (Sharifi and Khavarian-Garmsir, 2020). This approach to urban resilience can lead to proactive planning, adjusting, adapting, and transforming operations at different scales and with long-time perspective. The existing and well-documented experiences of international networks such as C40 Cities and the 100 Resilient Cities may offer valid and promising insights in this regard (Acuto, 2020). Thus, when a crisis occurs, a resilient urban approach needs to understand and explore the linkages between several and cascading hazards since a pandemic, like other crisis, presents many dimensions. Starting from the building-systems, moving then to the mobility one, this pandemic experience underlined different degrees of "resilience-capacity" to deal with new social-needs and preferences provoked by COVID-19. Therefore, only through a proactive approach it is possible to predict and manage the multi-hazard scenarios that may follow, identifying possible domino effects.

In a nutshell (see Figure 23), it can be stated that COVID-19 is demonstrating that the global health crisis cannot be solved exclusively by sectoral technical solutions, despite interesting findings are actually emerging also from each sector. In this context, while some common patterns can be observed, growing evidence indicates that impacts and response mechanisms differ from context to context, and thus, it is not always possible nor immediate to provide the same recommendations that can be applied to different urban systems. To support a real shift and adopt a resilient paradigm, urbanized contexts need an awareness of their overall system and performance level. In this broad understanding, insights should space from health, wellbeing and environment, to population features, economy, society, infrastructure and digitalisation, favouring connections between decision and policymakers, technical experts and professionals, scientists and people. Investments in resilience go far beyond the traditional and close issues of costs, time and quantity. Rather, it is mainly a **horizontal effort** made of learning from experiences and mistakes, listening to new social, environmental, design and economic needs, integrating new knowledge and providing new opportunities to integrate global uncertainties with urban future scenarios. The COVID-19 pandemic demonstrates not only that an integrated response, where the spatial component is integrated with the socio-economic aspects, can work, but also that a global concern needs a practical solution that works for everybody, sometimes in different and specific ways that work synergically. Thus, according to the theories presented, a resilient system and place should be able to maintain a certain stability within its overall structure and to allow a certain degree of self-organization, change and freedom at lower scales of smaller components. Indeed, **a system that persists without changing through time is not alive**: to be so, the system has to adapt and change somehow. This process can be recognised for instance in some changes that several US metropolitan counties adopted along the epidemic experiences overmentioned, introducing for instance new concepts of density, reducing the interest in urban expansion, improving the health department services at local scales, the quarantine procedures, the tracking services, the water supply network, the broader avenues and streets, and so on. Thus, looking at these novelties, it is possible to comment that to date the US metropolitan counties response to COVID-19 is not highly resilient, even though the crisis experience has undoubtedly introduced some elements, new needs and phenomena that will lead to some changes and re-organization. In this sense, it is probably still too early to see tangible changes, but in terms of spatial and functional dimensions, it is undeniably struggling to provide new forms, settlements and requirements whose purposes are different from those they were originally planned and designed for. However, to analyse this aspect more in detail, further developments of this study could for instance involve the updated of the "static data/variables" according to the new information collected during (and after) the pandemic-waves, in order to highlight the new static trends in terms of population density, housing, mobility habits, working categories, teleworking options, and so on. Indeed, the integration of this updated information with the Coronavirus diffusion within different US metropolitan counties may already highlight the capacity of urban systems to integrate this change and to somehow "merge" the extraordinary and the ordinary, constantly adapting.

Lessons learnt in Bullet-points

Figure 23 – The five major lessons learnt from this thesis in bullet points
(Source: personal elaboration)

** * * The End * * **

SUMMARY OF THE WORK AND PhD PROCESS

> *It is good to have an end to journey toward,*
> *but it is the journey that matters, in the end.*
>
> Ursula K. Le Guin, 1969, The Left Hand of Darkness

In conclusion, the sixth and last part (Chapter 6) summarizes the thesis work and points out the main steps of the PhD process. The summary follows the "zoom-in" style of the thesis: from the general and theoretical level, to the specific discussion on coronavirus-crisis impacting on a geographical context. This approach favours the presentation of the main findings, their utility in both academic and expert discussion, and of their limitations: indeed, from the beginning of the thesis, some weaknesses came out and have to be (re)discussed also at the end of the work. Light on these parts will underline some possible future developments of the thesis in the conclusion, opening new doors for research and implementation.

Finally, an overview of the three years PhD process is provided.

A. Research outcomes

The current thesis aimed to understand and deepen the relationship between population size/density and COVID-19 experience not only in theory but also in the aftermath of a crisis-experience, hence improving a niche field to integrate the main findings in planning theory and practice, possibly adopting a resilient approach. Despite the structured geographical contexts in which the COVID-19 pandemic experience is analysed, **the diffusion behaviour of the pandemic and its impacts demonstrate the necessity to incorporate explicitly the element of change and the dimension of space and time in the understanding of cities**. In fact, in this sense, one of the main lessons learnt from this experience is that systems, meant as complex systems, have to accept that 21st century is "challenging" the Anthropocene, offering new crisis regimes in a sort of "new reality" to co-exist with. The imperative, as largely demonstrated by this experience also at the local urban level, is to find ways to accept the presence of the change-element in our urban setting and dynamics, and find new ways to live with or adapt to them.

At the beginning of the work (Chapters 2 and 3), four steps were developed:

1. An overview on the literature on "diffusion theory" and "complex urban systems" first and then on "density and population size" in time of pandemic, since they represent two undeniable characteristics of any urban space which firstly enter in contact with any kind of shocks;

2. A collection of data, based on literature and available information in order to develop a reliable and strong case study, on which building the quantitative analysis;

3. A processing data phase, where several features were put in relationship through regression analysis and other statistical tests, in order to investigate the role covered by population features on COVID-19 distribution;

4. The demonstration of the role of density and population size in dealing with the condition of crisis and uncertainty provoked by the rapid spread of an unknown infection, and thus what can be extrapolated for planning implications and further research.

With reference to the previous points, the analysis-outcomes demonstrate that despite there are some undeniable correlations between density and disease vectors, to date it is also evident that among the greatest contributors to infection density itself, it is rather the manner in which density is expressed. Even though county-scale turned out not to be the most fitting one, those living in safe spaces, with resources, able to shift easily to work from home and access good healthcare will be less vulnerable than people living in environments of "bad" or dubious density, with few resources, inadequate services and poor social distance to ensure good sanitation. Additionally, also the choices introduced by local government and national states and the resources already in place had an impact on the infection and death rates. As such, over-simplified policies, which try to associate density with the spread of disease without taking context into consideration, may introduce worse matters and unintentionally cause greater devastation than the pandemic itself.

To deepen this aspect, several fields were put closer: the diffusion theory according to the geographical interpretation, the socio-ecological system and complexity theories referred to urban dimension, and the planning field. Thus, in Chapter 2 some basic principles related to the diffusion-process and behaviour were introduced, then dynamics of change in complex systems were described, focusing on models like the Adaptive Cycle and Panarchy (Gunderson and Holling, 2001). This step provided interesting highlights that also the metropolitan counties, as other types of complex adaptive systems, can be read and studied as a complex, multi-layered and spatial-temporal system where the dynamic behaviour follows its spatial-temporal flows, and thus that a resilient perspective could be successfully used to understand all this in the planning theory and practice.

By focusing then on the COVID-19 crisis experience in the context of US Metropolitan Counties, the two population attributes and other socio-economic features were successively collected in measurable proxies, covering both spatial and socio-economic metrics, observable and available at that scale-level. These proxies somehow made a more immediate connection with the COVID-19 distribution, favouring its understanding from both a quantitative and qualitative point of view, and opening a wider debate on change, crisis phenomena and complexity in current and future cities.

Moving finally to the more practical steps, the operative part of the work merged the theoretical framework and outcomes with a practical crisis context, trying then to connect the case study outcomes with the original attributes of being and process. In this sense, the study shows a weak relationship between population variables and COVID-19 or, better said, a complex relationship where **results are not net nor definitive,** also because of their high degree of inter-relation verified through statistical tests. In fact, the still provisional and incomplete condition of available data suggests that further reflections and findings may be added in the future. Moreover, even though further research is recommended and needed, the study is replicable to empirical research and applicable to other case studies and local scales.

Another contribution and general outcome that can be pointed out refers to the preliminary findings arising from the case study. In fact, whilst the main ambition of the case study analysis was to shed light on the relationship between the population variables and COVID-19 distribution, this case study experience also analysed the behaviour and efficacy of different urban features under a pandemic stress. On one side, the qualitative profile of the study allows identifying the key drivers of change within a complex spatial urban system; while on the other, the quantitative analysis of proxies allows an immediate comparison between different features-weights at a comparable spatial resolution.

These findings allow also to conclude that, as previously mentioned (Chapter 5), visible changes may take a long-time to be visible while smaller and more functional transformations are already taking place.

B. Limitations of the work

This paragraph points out the broad limitations of this work, referring to the whole framework (theoretical and practical) in which the thesis process has been developed. In fact, despite this is not the first experiment that introduces population features in the COVID-19 experience (Carozzi, 2020; Hamidi et al., 2020; Whittle et al., 2020), the effort to understand their role in the pandemic to support future resilient planning is a delicate exercise, not far from potential critics and contradictions. For these reasons then, at the end of the work it is possible to identify some limitations:

_ Firstly, even though the theories suggest using very dynamic models to analyse the built-environment, like the adaptive cycle and the Panarchy model (Gunderson and Holling, 2001), urbanized contexts and ecosystems do not easily correspond in practice. Metropolitan areas and cites are artificial systems, outcomes of "*aims, intentions, plays, design and engineering*" (Portugali, 2011, p.228), **places where planning rules**. However, as clearly demonstrated along this thesis, exactly like natural and ecological systems they are not only top-down planned, but sometimes driven by **bottom-up conditions, self-organization processes and unexpected stressors**, that create crisis, emergence and confusion. Thus, cities are both the product of single-minded decisions at top level, but also the result of multiple local, cunning and individual decisions (Portugali, 2011, Campbell, 2011). This is the challenging background in which this work tries to understand crisis phenomenon in urban contexts, aiming to understand the impacts on and dynamics over time during (and after) the COVID-19 diffusion process.

_ Secondly, since around planning in and after the COVID-19 crisis there is still a lot of discussion and poor application, the presented work allows only a partial definition of the implications in planning. Hence, as already clarified in Chapter 3 and 4, **the selected dependent variables do not pretend to be fully comprehensive**, neither does the methodology applied to read them at US metropolitan level. Rather, the presented approach allows to be repeated and applied also in other urbanized contexts affected by pandemic crisis, while remaining open to any content-contributions. This aspect can turn from a limitation to a long-term occasion to make progresses in the research, through the identification and application of new methods and features to improve this lack.

_ Third, considering that the urban features concurring in this study are mainly referred to the two population features addressed, an awareness to point out is that this work has turned its attention on those aspects more strictly related to population geography. This means that, whilst recognizing their key role, **this work made inevitably a selection**, having to do with space, its closest indirect features, and an unexpected pandemic crisis behaving differently in space and time. Nevertheless, this aspect should not represent a real limitation but rather a key awareness of the researcher: the social, economic and environmental impacts of the COVID-19 crisis cannot be addressed and analysed from the study of form alone, but the outcomes from Chapter 4 and 5 can support the understanding of broader future evolutions and changes.

_ Last but not least, both the theoretical and practical parts of this work are not able – neither in the condition – to make any projections of how urban form changes after the COVID-19 experience will also influence the socio-economic dynamics, especially in a complex urbanised context as the US metropolitan county one. Better thinking in fact, when addressing some population or geographical elements and their relationships with a certain phenomenon, the effects on the system inevitably touch also the social, economic and environmental processes already in place. This dynamic stresses that if population density and size are not directly impacting COVID-19 behaviour, in turn they cover a key role in favouring evolutionary processes of demographic, socio-economic and environmental transformation with time (Feliciotti, 2018). This sort of **“conditional” role** (Bobkova et al., 2017) covered by population features has not only to be considered when interpreting these research outcomes, but also when reflecting on how urban planners and designers may re-organize their disciplines after COVID-19 through their pragmatical work.

C. The PhD process

As introduced in the initial narrative of this work, this PhD activity did not follow a very linear process, as several changes occurred, both internal and external. Nonetheless, it came to a conclusion, while completing all the tasks required and adding some extra activities.

The following Gantt chart (Chart 13) reports the whole PhD three-year program. As evident from the chart, the research work was developed through a long literature review process, with the related boundaries and research goals and question definition. This process was also supported by the R3C PhD Lab, whose five meetings between March and June 2019, supported the definition of the research topic, the theoretical discussion, the critical understanding of potential research limitations and possible improvements. Last but not least, this stage found a more complete fulfilment after the referee's comments, which added new integrations and contributions to the work.

In parallel to this process, the definition of the case study had a double moment: in a first step on the program, the study focused on a single case at urban level, while in a second step, considering the strong limitations observed in the first attempt, the work passed to a broader scale – that of US metropolitan counties – where both literature and data were supporting the elaboration process. This second part of the work, much more intense and difficult, was then followed by the analysis and validation of results, which can still be improved in some parts.

While the thesis started to become a written and evolving document from the very beginning of the PhD, two other moments characterized specifically the three year-program: the visiting period abroad to White Arkitekter Firm in Stockholm (Sweden), to deepen the topic of resilience applied to urban planning and design; and the visiting period to the Chalmers University of Technology in Gothenburg (Sweden), to explore and understand the use of the existing spatial and analysis tools and find a good case study to develop.

However, as evident also from this thesis, the COVID-19 outbreak limited all these ambitions and forced a review of the research-topic and the related timing to develop it.

Passing to the courses to follow and exams to pass, both requirements for Soft and Hard Skills courses have been passed till today. More specifically: 214 hours up to 100 of hard skills – mainly selected according to the theoretical and methodological requirements – are passed till today; while 44 hours up to 40 of soft skills – mainly selected according to the methodological and transversal requirements and gaps – are passed till today.

Also the publication minimum requirement has been reached, and this is the full list of published works:

Buffa, Alessandra; (2022) *Resilient urban form addressing pandemic crisis.* In: Annual Conference Proceedings of the XXVIII International Seminar on Urban Form. University of Strathclyde Publishing, Glasgow, pp. 1199-1215. ISBN 9781914241161

Pede, Elena; Barbato, Giuliana; Buffa, Alessandra; Ellena, Marta; Mercogliano, Paola; ... (2022) Mountain tourism facing climate change. Assessing risks and opportunities in the Italian Alps.. In: TEMA, vol. 15, pp. 25-47. ISSN 1970-9870

Buffa, Alessandra; Mohabat Doost, Danial; Brunetta, Grazia; Voghera, Angioletta (2020) Integrating Resilience Concept and Urban Morphology. A contradictory merging attempt or a promising combination?. In: URBAN SUBSTRATA & CITY REGENERATION Morphological legacies and design tools, Roma, 19-22 February 2020, pp. 741-755. ISBN: 9788894118889

Ellena, Marta; Ricciardi, Guglielmo; Barbato, Giuliana; Buffa, Alessandra; Villani, ... (2020) Past and future hydrogeological risk assessment under climate change conditions over urban settlements and infrastructure systems: the case of a sub-regional area of Piedmont, Italy. In: NATURAL HAZARDS, vol. 102, pp. 275-305. ISSN 1573-0840

Mohabat Doost, Danial; Buffa, Alessandra; Brunetta, Grazia; Salata, Stefano; Mutani, ... (2020) Mainstreaming Energetic Resilience by Morphological Assessment in Ordinary Land Use Planning. The Case Study of Moncalieri, Turin (Italy). In: SUSTAINABILITY, vol. 12, pp. 1-25. ISSN 2071-1050.

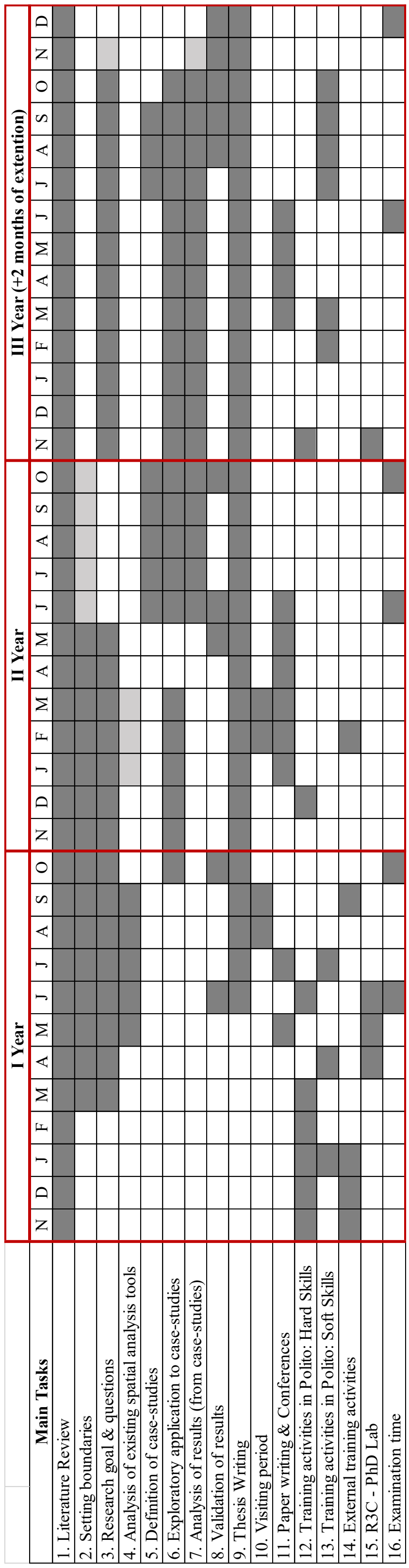

Chart 13 - Gantt chart reporting the three-year PhD program, the related activities and development-periods (Source: personal elaboration).

D. Further steps of the research

Once that the final version of the thesis will be updated and sent to the Commission of five Evaluators, then the work will be presented during the Final Dissertation in front of the Commission, and made available online to the scientific community and public.

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Doctoral Dissertation
Doctoral Program in Urban and Regional Development (XXXIV Cycle)

The role of density and population size in the pandemic-crisis experience of Covid-19

* * * *

Attachment Section

Attachment Section

This addendum of the thesis contains three sections that deepen (1) the work developed for the COVID-19 data analysis, collected along different timings under the pandemic emergency; (2) the work developed for the simple linear regression analysis which, despite not influential on the final results, is still interesting to isolate indicators and see their correlation with the COVID-19 variables; and (3) the statistical tests developed to deepen the Correlation issue among couples of independent variables.

<u>Section 1</u>

This part of the attached document contains the Maps of reported COVID-19 Cases and Deaths in US Metropolitan Counties collected along different time-period of the study (and partly presented in the Chapter 4 of the thesis). They can be useful to make a comparison among pandemic cases and deaths along time.

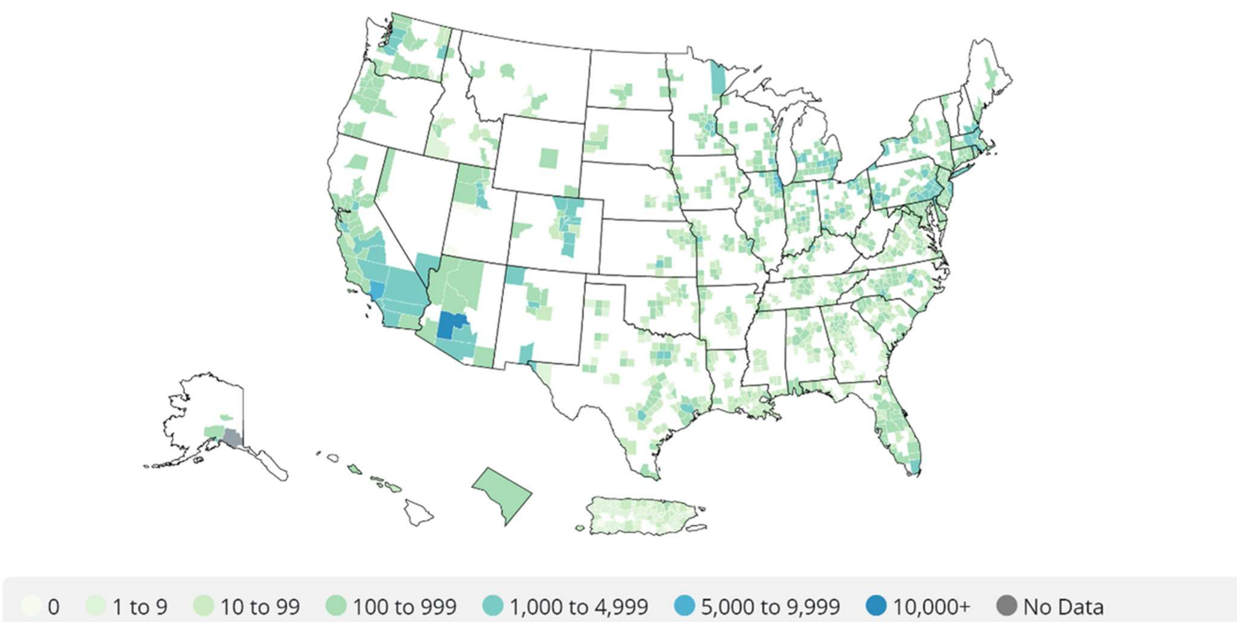

Figure 1 - Reported COVID-19 cases in US Metropolitan Counties -– Time Period: Sat Nov 20 2021 -– Fri Nov 26 2021 (Source: covid.cdc.gov)

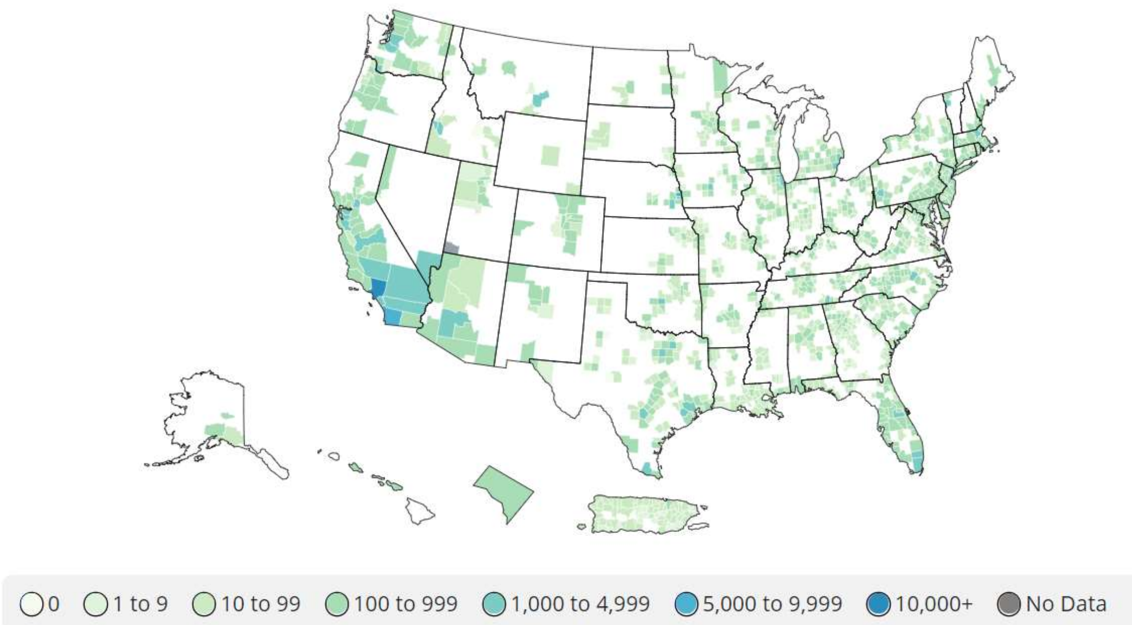

Figure 2 - Reported COVID-19 cases in US Metropolitan Counties -– Time Period: Sat Feb 26 2022 -– Fri Mar 04 2022 (Source: covid.cdc.gov)

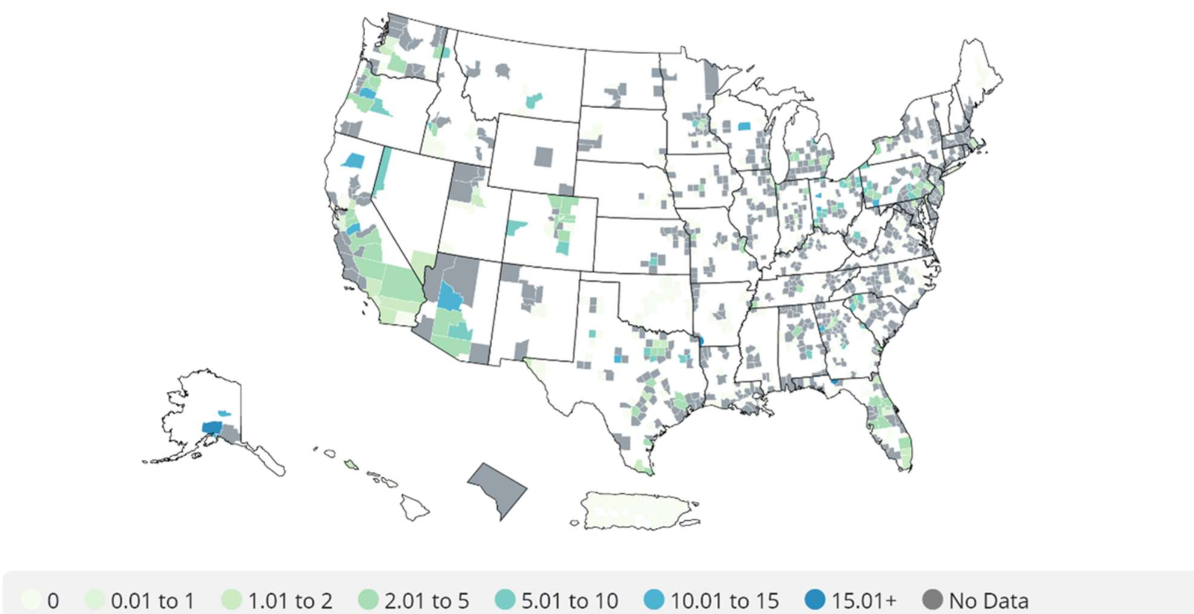

Figure 3 - Reported COVID-19 deaths per 100’000 population in US Metropolitan Counties -– Time Period: Sat Nov 20 2021 -– Fri Nov 26 2021 (Source: covid.cdc.gov)

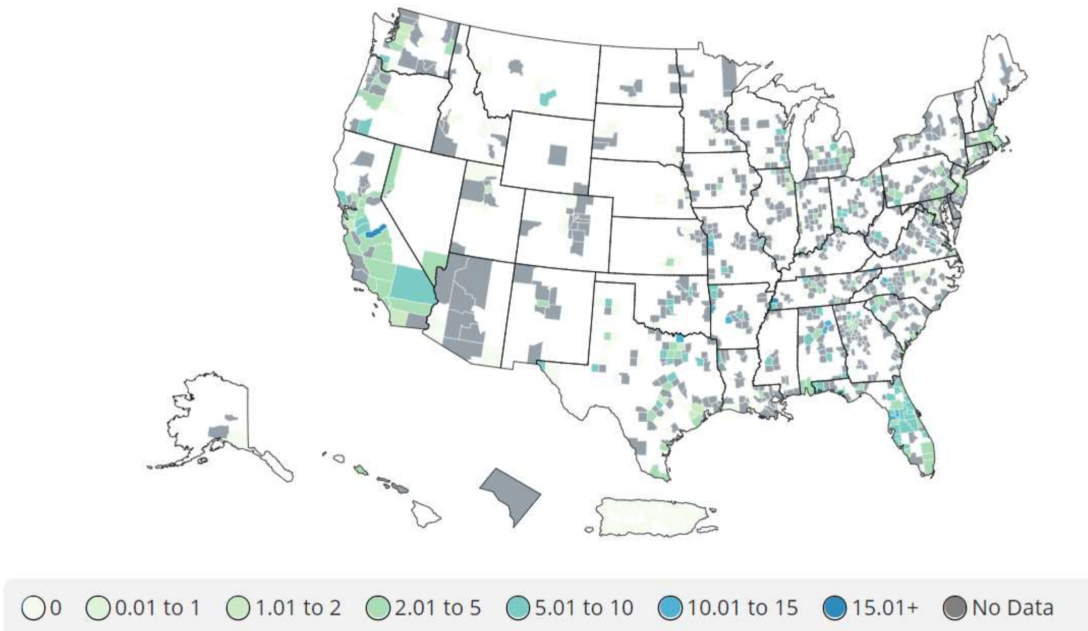

Figure 4 - Reported COVID-19 deaths per 100'000 population in US Metropolitan Counties – Time Period: Sat Feb 26 2022 -– Fri Mar 04 2022 (Source: covid.cdc.gov)

Section 2

This section of the attached work contains those simple linear regression attempts, whose results were not relevant to understand and improve the topic and hypothesis of the thesis.

a. COVID-19 cases and deaths in relation to income

According to Quinn, Kumar and other colleagues (Quinn & Kumar, 2014; Quinn et al., 2011), among the other factors, a significant role is played by the incomes. Indeed, it seems that low-income populations show higher exposure to contagions and have lower access to health care once the disease has developed (Charts 1 and 2). Furthermore, as already mentioned, usually lower income citizens are more likely to keep on travelling in the city or cross public spaces also during the crisis, because of work obligations.

In the specific contest of the US metropolitan counties, the number of positive cases and the number of deaths (as observed in the summer 2021) are put in relation with the poverty and median income values (updated to 2019).

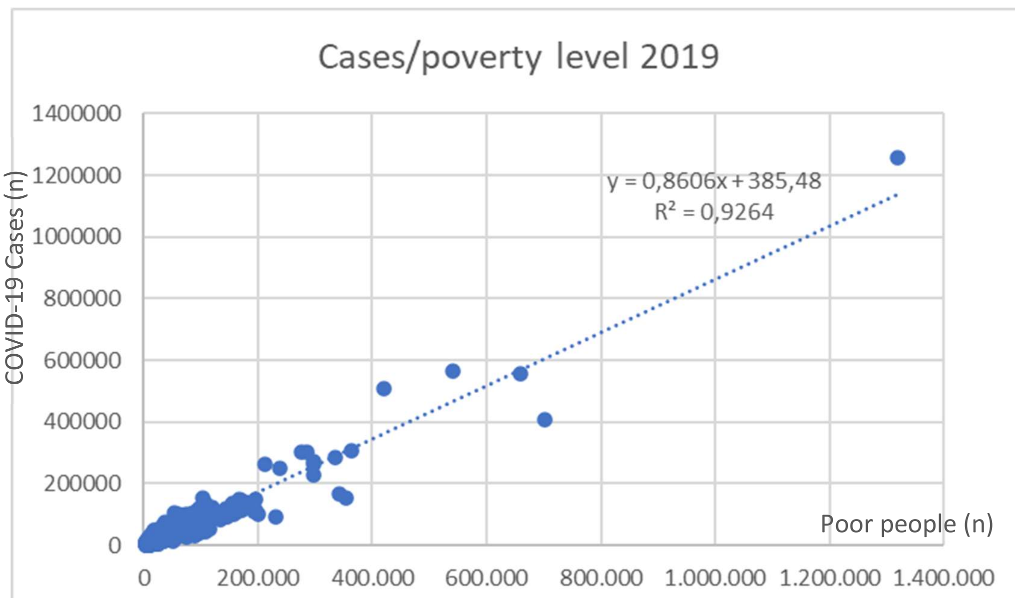

Chart 1 – Cumulative number of COVID-19 cases in relation to poverty level (2019) by US metropolitan counties (Source: Personal elaboration of CDC.gov and GitHub databases).

As evident from this first chart, most infected people are also those with lower incomes. The relationship between COVID-19 cases and incomes is particularly strong and leads to several reflections.

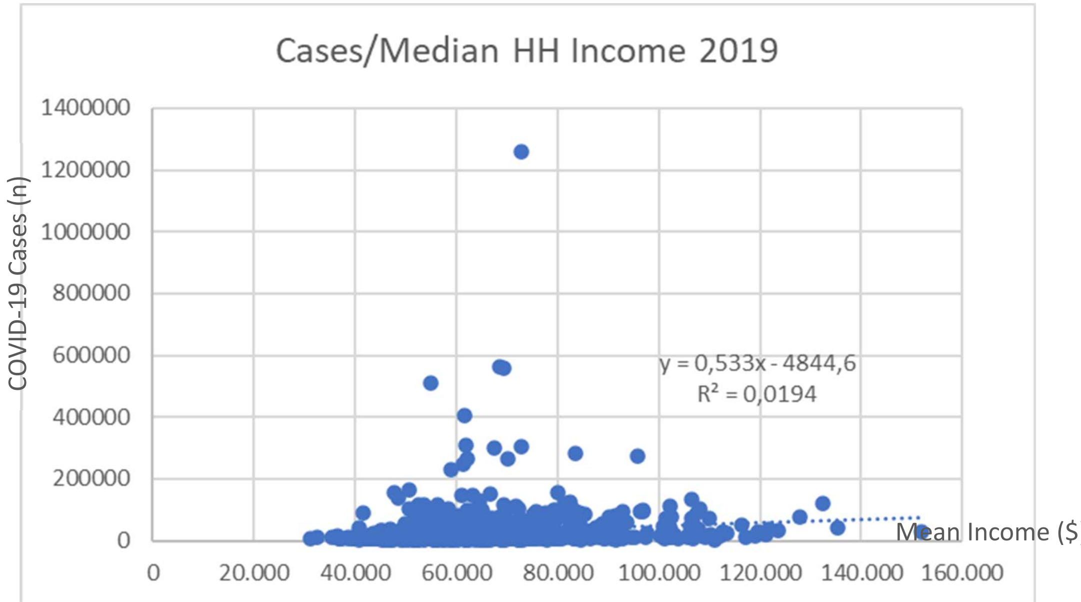

Chart 2 – Cumulative number of COVID-19 cases in relation to the median household income (2019) by US metropolitan counties (Source: Personal elaboration of CDC.gov and GitHub databases).

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According to Moroko et al., (2020), highest rates of COVID-19 cases and deaths can be generalized as working-class mainly active in service workers and other "essential services", where college degree is not required and pay wages are just above the poverty levels.

This issue, combined with other proxies more focused on the occupation categories most affected, housing conditions, the mobility patterns, and, in general, the spatial and socio-economic conditions of each metropolitan county, can become a central topic for policy-makers dealing with the pandemic outbreak. For instance, they may offer more help and alternative shelters during the crisis to reduce the gap between different social groups (Almagro and Orane-Hutchinson, 2020). In any case, further links and reflections on this topic will be provided in Chapter 5.

b. COVID-19 cases and deaths in relation to the low education level (2015-2019)

As previously emerged from observations and literature, COVID-19 diffusion is closely related to the education level of adults in a negative way. Thus, the following charts (Chart 3 – Chart 4) refer to the relationship between those people having less than a high school diploma (between 2015-2019, according to the US Census Bureau from 1970 to 2000 and the 2015-19 American Community Survey 5-yr average county level estimate) and COVID-19 variables. As visible, lower educated people are more likely to get infected by the virus. This relationship is less strong when observing deaths. Interestingly, the trend about COVID-cases was also observed by a Canadian report published by Statistics Canada (www.statcan.gc.ca) in 2020, where results on workers and infection pointed out that given that workers with higher levels of education are more likely to be in jobs amenable to telework, the major risk falls mainly on the lower educated people. In fact, data from Canada point out that among workers who did not telework before the COVID-19 emergency, nearly the 33% of those with at least a bachelor's degree teleworked in June 2020. The proportion became even higher for those whose highest level of education: the rate increased to 38%. On the contrary, pre-pandemic commuters whose level of education was below the bachelor level were less likely to have switched to teleworking, just the 11%. These results, the study concludes, also favour to understand the relationship between metropolitan areas, presence of telework and COVID-19 behaviours, as workers in larger metropolitan areas are also more likely to have a higher level of education and usually to get less infected.

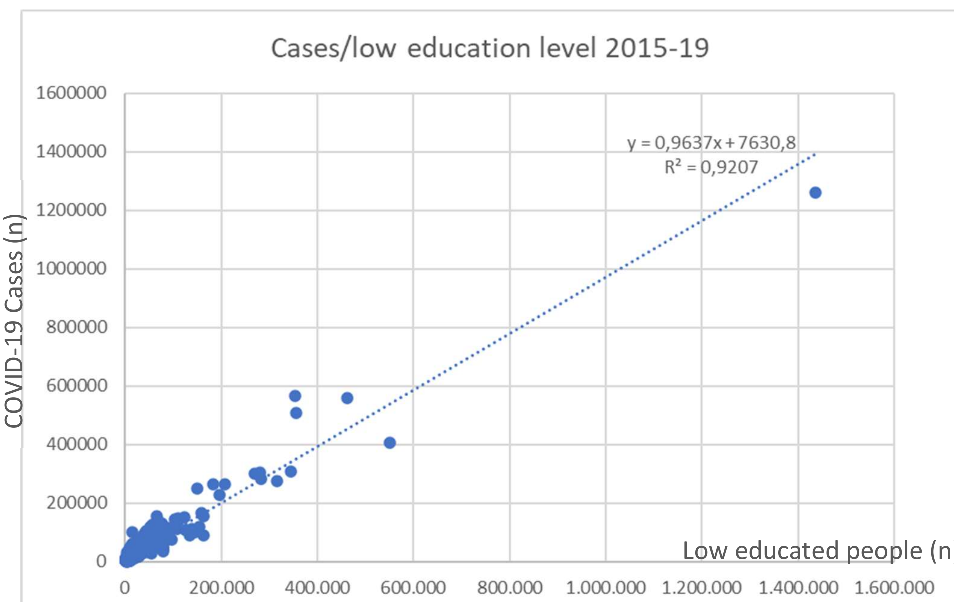

Chart 3 – Cumulative number of COVID-19 cases (on 28th of July 2021) in relation to the rate of low educated people by US metropolitan counties (Source: Personal elaboration of CDC.gov and GitHub databases).

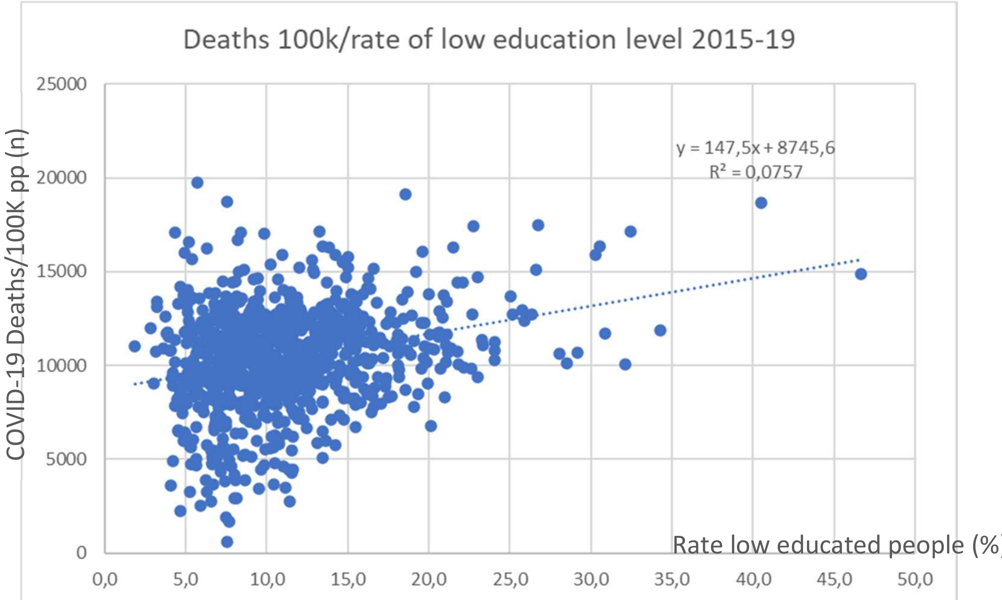

Chart 4 – Cumulative number of COVID-19 deaths on 100k people (on 28th of July 2021) in relation to the rate of low educated people by US metropolitan counties (Source: Personal elaboration of CDC.gov and GitHub databases).

What these data suggest, in line with other findings (see the study from University of Kansas, "Vulnerable populations and misinformation: A mixed-methods approach to underserved older adults' online information assessment", about the relationship between low educated people, misinformation and COVID-19 rise) underline that lower education levels of population usually are more vulnerable to the infection, also because of the low access to information they have. However, as other studies state, low education needs to be read together with other socio-economic variables, to understand also the role of income, race and job-occupation.

c. COVID-19 cases and deaths in relation to unemployed people (2020)

Recent observations on the socio-economic conditions of people that got infection demonstrate that COVID-19 tends to hit more the lower-income Americans. Job loss and financial struggles in fact are more prevalent among certain demographic groups, that during the pandemic turned positive more frequently. This phenomenon can be observed at both urban and county level, as demonstrated by the following charts (Chart 5 and Chart 6), where the R^2 is particularly strong and the relationship between positive cases and unemployed (updated in 2020) is very positive. As pointed out by Parker et al. (2020), in addition to unemployment, also education levels and ethnicity can make a difference, especially in terms of culture and economic capacity to save money, to access to health services and to work at higher levels.

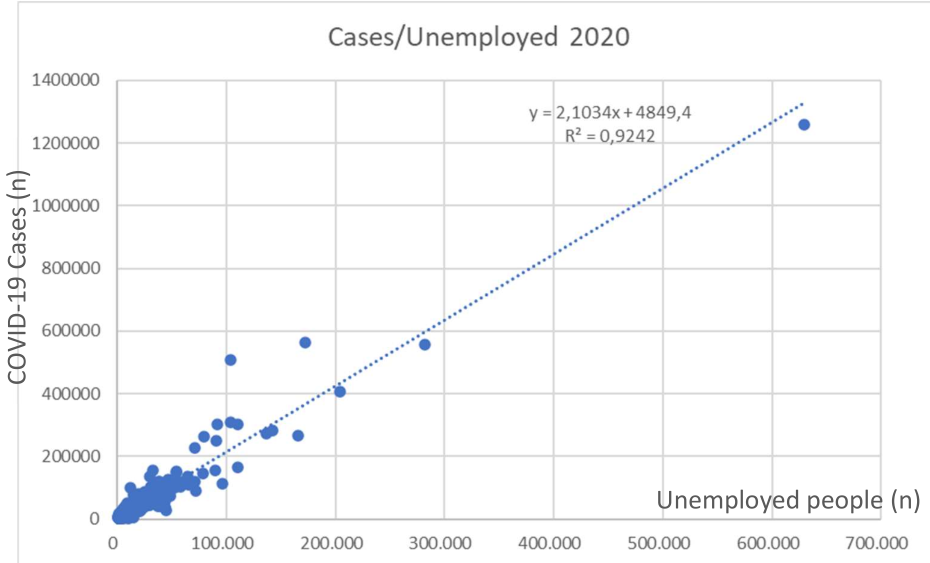

Chart 5 – Cumulative number of COVID-19 cases (on 28th of July 2021) in relation to the rate of unemployed people by US metropolitan counties in 2020 (Source: Personal elaboration of CDC.gov and GitHub databases).

Among lower-income adults, already before the pandemic there were several economic troubles, mainly related to bills-payments, rent or mortgage payments, that were probably pressing these families and people from long time. To be sure, it would be interesting to get updated data about this point and compare unemployment rate along different COVID-19 waves and see how the relationship with positivity changes in time. Due to lack of data, this ambition can be considered for further steps of the analysis on this topic.

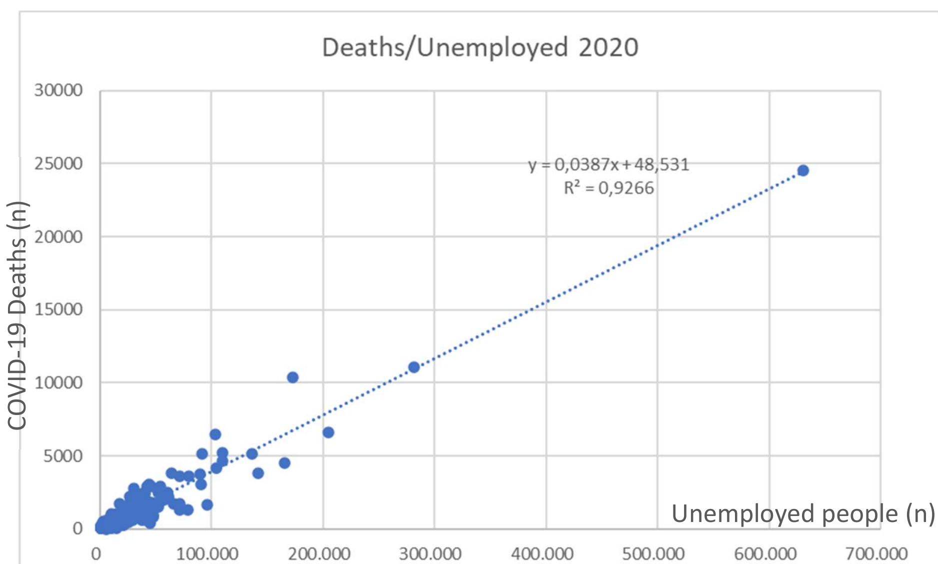

Chart 6 – Cumulative number of COVID-19 deaths (on 28th of July 2021) in relation to the rate of unemployed people by US metropolitan counties in 2020 (Source: Personal elaboration of CDC.gov and GitHub databases).

Similarly to the previous data, also in terms of deaths, the relationship between unemployed people at US metropolitan county level and deaths is highly positive. The reasons are mostly the same, but extra words can be added on the difficulty of some communities to have access to private health insurance and thus, to receive proper hospital treatments once that the infection gets worser and worser.

d. COVID-19 cases and deaths in relation to races (2020)

The Coronavirus is inequitably impacting certain communities more than others. Several studies point out that in the US, the infection infected people by racial and ethnic groups, revealing the deep inequalities in the probability of dying (see the work of the APM Research Lab, 2021, https://www.apmresearchlab.org/covid/deaths-by-race; and the Commonwealth Fund analysis, 2020, https://doi.org/10.26099/gjcn-1z31). When referring to "ethnic minorities" as a group, the reference goes to Asian, Black, Mixed and Other ethnic groups compared to White ethnic groups. Due to the research ambitions, in this contest some minor classes have been excluded, since their role in the pandemic scenario was quite uninfluential. In a nutshell, Black Americans suffered the highest rates of loss, with Black and Latino Americans dying at least 2.7 times more than their White neighbours. Strangely from common beliefs and circulating tears, Asians do not experienced such a strong positivity or mortality disadvantage as superficially expected or believed (Charts 7 and Chart 8).

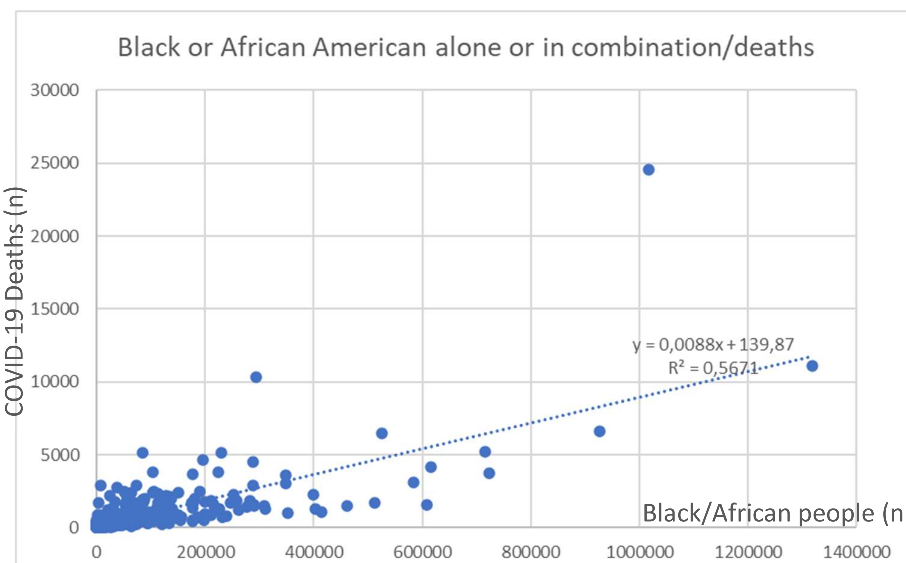

Chart 7 – Cumulative number of COVID-19 deaths (on 28th of July 2021) in relation to the number of Black or African alone or in combination by US metropolitan counties in 2020 (Source: Personal elaboration of CDC.gov and GitHub databases).

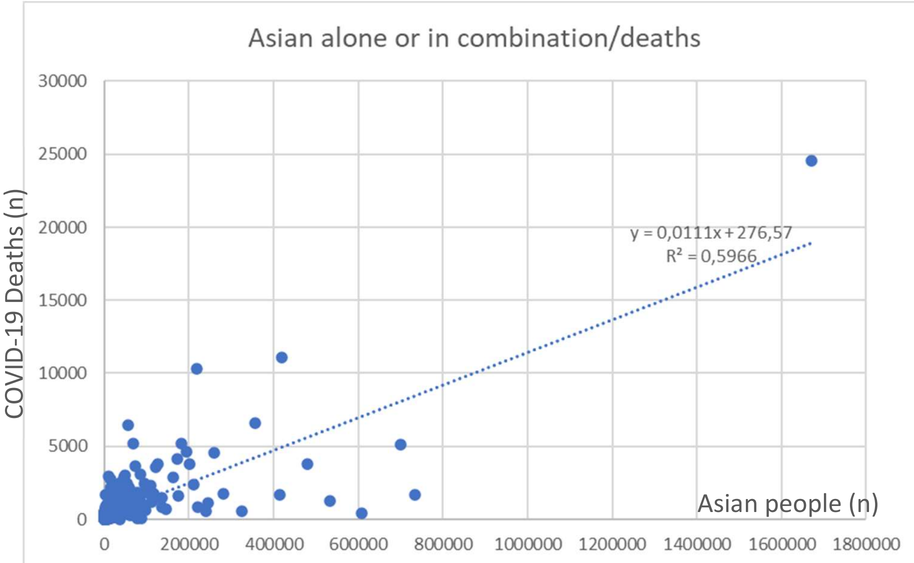

Chart 8 – Cumulative number of COVID-19 deaths (on 28th of July 2021) in relation to the number of Asian alone or in combination by US metropolitan counties in 2020 (Source: Personal elaboration of CDC.gov and GitHub databases).

Nonetheless, these results – based on absolute deaths numbers, can lead to a partial understanding of the phenomenon. A more precise understanding should integrate racial groups with their economic, employment and education situations and, importantly, their access to health care.

Section 3

This section of the attached work contains the most relevant outcomes obtained by the Correlation analysis through Pearson and Student's t-tests. They mainly refer to the Excel analysis developed starting from both the Multiple linear regression analysis developed for COVID-19 cases and deaths per capita (without the outliers) and the Logarithmic regression analysis developed for COVID-19 cases and deaths per capita (without the outliers). Only "High" and "Moderate" Correlation values have been considered, in both scenarios.

a. **Database used: Multiple linear regression analysis developed for COVID-19 cases and deaths per capita (without the outliers)** (A.2, B.2 – see the Thesis)

FOCUS ON: POPULATION SIZE and the most relevant Correlations

a.1 Correlation between Population size and Population density

Correlaz t-Pearson	**0,617169727**	Moderate Correlation
t-Student	**1,25E-187**	Prob. of correlation occurred by chance: ver low
Variance Pop	*5991360016,39*	
Variance Dens	*30624,95*	
IV par t-Student	*3*	

a.2 Correlation between Population size and Unemployment levels

POP		
Correlaz t-Pearson	**0,945035887**	High Correlation
t-Student	**1,38E-180**	Prob. of correlation occurred by chance: ver low
Variance Pop	*5991360016,39*	
Variance Unemployment	*10517714,69*	*Va*
IV par t-Student	*3*	

a.3 Correlation between Population size and Whites

POP		
Correlaz t-Pearson	**0,980414057**	High Correlation
t-Student	**4,71E-04**	Prob. of correlation occurred by chance: ver low
Variance Pop	*5991360016,39*	
Variance Whites	*5131087663,95*	
IV par t-Student	*3*	

a.4 Correlation between Population size and Asians

POP				
Correlaz t-Pearson	**0,770434174**	Moderate/High Correlation		
t-Student	**1,16E-182**	Prob. of correlation occurred by chance: ver low		
Variance Pop	*5991360016,39*			
Variance Asians	*14733932,73*			V
IV par t-Student	*3*			

a.5 Correlation between Population size and Commuting Flows

POP					
Correlaz t-Pearson	**0,980823108**	High Correlation			
t-Student	**2,03E-78**	Prob. of correlation occurred by chance: ver low			
Variance Pop	*5991360016,39*				
'ariance Comm Flows	*1413558507,31*				
IV par t-Student	*3*				

a.6 Correlation between Population size and Poverty levels

POP					
Correlaz t-Pearson	**0,835571148**	High Correlation			
t-Student	**5,92E-162**	Prob. of correlation occurred by chance: ver low			
Variance Pop	*5991360016,39*				
Variance Pov levels	*96975872,74*				
IV par t-Student	*3*				

a.7 Correlation between Population size and Low Education levels

POP					
Correlaz t-Pearson	**0,790318605**	High Correlation			
t-Student	**8,09E-173**	Prob. of correlation occurred by chance: ver low			
Variance Pop	*5991360016,39*				
Variance Low Ed lev	*32386086,58*				
IV par t-Student	*3*				

a.8 Correlation between Population size and High Education levels

POP						
Correlaz t-Pearson	**0,920243428**	High Correlation				
t-Student	**1,75E-145**	Prob. of correlation occurred by chance: ver low				
Variance Pop	*5991360016,39*					
Variance High Ed lev	*436019406,90*					
IV par t-Student	*3*					

FOCUS ON: POPULATION DENSITY and the most relevant Correlations

a.9 Correlation between Population density and Whites

DENS					
Correlaz t-Pearson	**0,588935574**	Moderate Correlation			
t-Student	**2,37E-178**	Prob. of correlation occurred by chance: ver low			
Variance Dens	*30624,95*				
Variance Whites	*5131087663,95*				
IV par t-Student	*3*				

a.10 Correlation between Population density and Commuting Flows

DENS					
Correlaz t-Pearson	**0,634995061**	Moderate Correlation			
t-Student	**2,20E-171**	Prob. of correlation occurred by chance: ver low			
Variance Dens	*30624,95*				
Variance Commuting F	*1413558507,31*				
IV par t-Student	*3*				

a.11 Correlation between Population density and High Education levels

DENS						
Correlaz t-Pearson	**0,598586572**	Moderate Correlation				
t-Student	**8,99E-125**	Prob. of correlation occurred by chance: ver low				
Variance Dens	*30624,95*					
Variance High Ed lev	*436019406,90*					
IV par t-Student	*3*					

b. **Database used: Logarithmic regression analysis developed for COVID-19 cases and deaths per capita (without the outliers)** (C.2, D.2 – see the Thesis)

FOCUS ON: LOG POPULATION SIZE and the most relevant Correlations

b.1 Correlation between LOG Population size and LOG Population density

Correlaz t-Pearson	**0,562501176**	Moderate Correlation
t-Student	**0,00E+00**	Prob. of correlation occurred by chance: ver low
Varianza Pop	*0,06*	
Varianza Dens	*0,15*	
IV par t-Student	*3*	

b.2 Correlation between LOG Population size and LOG Unemployment levels

POP			
Correlaz t-Pearson	**0,9457708**	High Correlation	
t-Student	**0,00E+00**	Prob. of correlation occurred by chance: ver low	
Varianza Pop	*0,06*		
Varianza Unemploy	*0,07*		
IV par t-Student	*2*		

b.3 Correlation between LOG Population size and LOG Asians

POP		
Correlaz t-Pearson	**0,82596424**	High Correlation
t-Student	**0,00E+00**	Prob. of correlation occurred by chance: ver low
Varianza Pop	*0,06*	
Varianza Asians	*0,20*	
IV par t-Student	*3*	

b.4 Correlation between LOG Population size and LOG Commuting Flows

POP		
Correlaz t-Pearson	**0,97896786**	High Correlation
t-Student	**0,00E+00**	Prob. of correlation occurred by chance: ver low
Varianza Pop	*0,06*	
Varianza Commuting	*0,06*	
IV par t-Student	*2*	

b.5 Correlation between LOG Population size and LOG Poverty levels

POP		
Correlaz t-Pearson	**0,828522361**	High Correlation
t-Student	**0,00E+00**	Prob. of correlation occurred by chance: ver low
Varianza Pop	*0,06*	
Varianza Poverty Levels	*0,06*	
IV par t-Student	*2*	

b.6 Correlation between LOG Population size and LOG Low Education levels

POP		
Correlaz t-Pearson	**0,761441059**	High Correlation
t-Student	**1,01E-156**	Prob. of correlation occurred by chance: ver low
Varianza Pop	*0,06*	
Varianza Low Educ Levels	*0,07*	
IV par t-Student	*2*	

b.7 Correlation between LOG Population size and LOG High Education levels

POP			
Correlaz t-Pearson	**0,911595375**	High Correlation	
t-Student	**4,81E-296**	Prob. of correlation occurred by chance: ver low	
Varianza Pop	*0,06*		
Varianza High Educ Levels	*0,11*		
IV par t-Student	*3*		

FOCUS ON: LOG POPULATION DENSITY and the most relevant Correlations

b.8 Correlation between LOG Population density and LOG Commuting Flows

DENS		
Correlaz t-Pearson	**0,578541967**	Moderate Correlation
t-Student	**0,00E+00**	Prob. of correlation occurred by chance: ver low
Varianza Dens	*0,15*	
Varianza Commuting	*0,06*	
IV par t-Student	*3*	

b.9 Correlation between LOG Population density and LOG High Education levels

DENS			
Correlaz t-Pearson	**0,558273026**	Moderate Correlation	
t-Student	**0,00E+00**	Prob. of correlation occurred by chance: ver low	
Varianza Dens	*0,15*		
Varianza High Educ Levels	*0,11*		
IV par t-Student	*3*		

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