Spatial congruency or mismatch? Analyzing the COVID-19 potential infection risk and urban density as businesses reopen

Abstract
Countries worldwide are reopening their businesses despite the continuing COVID-19 crisis and the emergence of new variants. In this context, knowing whether the reopening of businesses at various locations exposes higher risk to the public is essential. Whether urban density correlates with the potential infection risk as concluded by previous studies of the COVID-19 pandemic remains unknown. In this study, taking the Macau Peninsula as a testbed, we first identified business locations for daily activities according to the latest point of interest (POI) data and generated the potential risk surface for COVID-19 infection. Then, using the cellular phone network and urban footprint data, we further analyzed the spatial relationship between COVID-19 potential risk and urban density of population and morphology through visual analytics. Results show that while some degree of spatial congruency exists between medium-risk peaks and urban density hotspots, apparent spatial mismatch exists for high-risk peaks, indicating that the traditional planning control based on urban density is inadequate for mitigating public health risks. POI-based spatial layout and configuration better reflecting business services and associated human activities are recommended in future planning and policy-making for more resilient cities in the post-pandemic era.

Keywords: COVID-19 Risk, Daily Activities, Point of Interests, Business Reopen, Urban Density, Spatial Relationship

1. Introduction

After nearly two years of fighting against COVID-19 with various lockdown or quarantine policies, countries worldwide are slowly rolling out their business reopening plans (Dockery, 2021; The New York Times, 2021). However, the crisis seems long-lasting with newly detected and more transmissible and lethal variants, causing more uncertainties and threats to the general public (Grubaugh et al., 2021). Reopened local businesses providing necessary services may expose new COVID-19 infection risk to their customers, who are alerted with cautions at this stage (CDC, 2020).

Meanwhile, whether urban density is a significant factor contributing to the contagious COVID-19 has been the subject of a heated debate along with the pandemic's development phases (Seidlein et al., 2021; Shen, 2021). Recent findings by urban planning scholars concluded that the infection rate is not significantly correlated with urban density, when controlling for metropolitan population size (Hamidi et al., 2020). Similar studies draw their conclusions by comparing and contrasting the relationship using fairly crude spatial measurement units (e.g., urban, suburban, rural, county, metro) and confirmed infection cases. Given that confirmed cases have already been quarantined and cured, understanding the spatial characteristics of potential risks possibly triggering new waves of infection as businesses reopen is urgent (O'Donoghue, 2021). To our knowledge, few studies have directly examined the spatial relationship between urban density and the potential infection risk of COVID-19 in a specific urban area using high-resolution spatial and updated business reopening data. In this regard, as a typical densely populated city in Asia, Macau is an ideal site to further explore whether spatial congruency or mismatch exists between urban density and infection risk in the context of the ongoing COVID-19 pandemic.

Public health experts ranked the likelihood of COVID-19 transmission and categorized different types of businesses by risk levels (Mlive, 2020). On the basis of this well-recognized categorization and ranking, we identified urban locations that host various businesses in the Macau Peninsula based on the latest point of interest (POI) data and explored the following research questions through spatial analysis: (1) Where do daily activities potentially expose people to COVID-19 infection risk as businesses reopen given that COVID-19 is likely to coexist with humans for a long time? (2) Does the potential infection risk of COVID-19 spatially correlate with urban density in terms of population and morphology? We hope that this research would not only help guide business reopening plans but also provide further insights into planning more resilient cities to cope with future public health emergencies, from Macau to the world.

2. Research methodology and data

Figure 1 shows the risk values for 36 essential business activities from hair salons to gyms ranked by public health experts. The potential risk rises from 1 (low) to 9 (high) considering common business characteristics, including

indoor/outdoor, social distance to each other, exposure time, compliance possibility, and individual risk (Mlive, 2020).
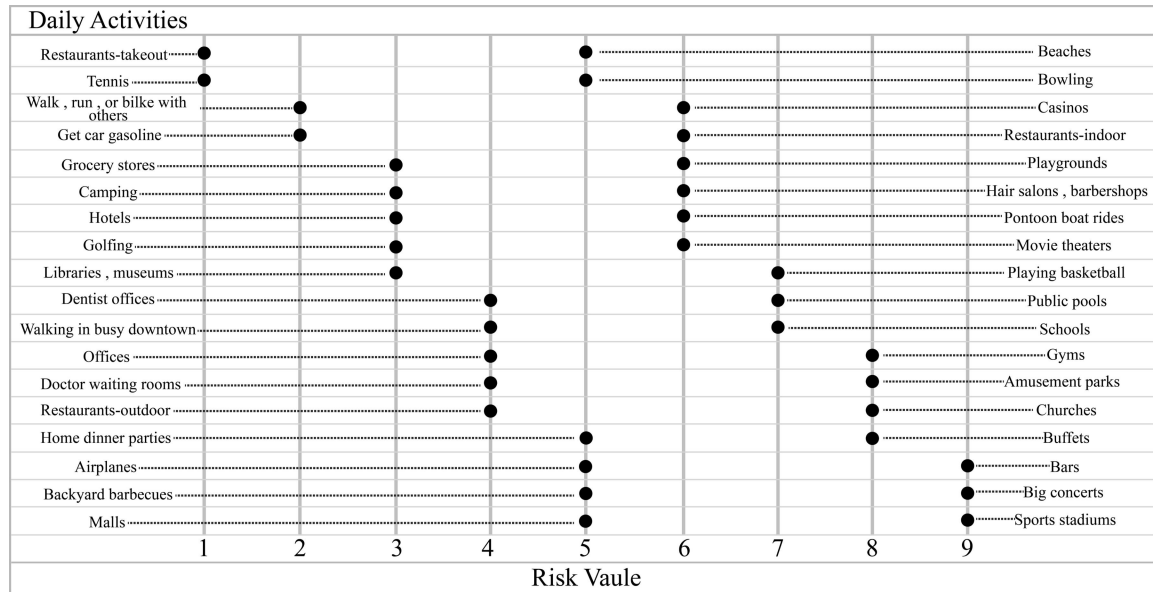
Fig. 1 Risk for 36 essential businesses

We geocoded the spatial locations for each of these 36 business activities in GIS on the basis of the latest POI data. We rendered the risk value to each of the points and generated the COVID-19 potential infection risk level surface on the basis of the Point Kriging method across the entire Macau Peninsular in Surfer (Golden Software, 2022).

$$G(j) = \sum_{i=1}^{N} W(ij) \times G(i),$$

where *G(j)* is the estimated risk level at the *j*th node, and *N* is the number to interpolate. *G(i)* is the risk value of the *i*th location, and *W(ij)* is the weight associated with *i*th value according to the distance between locations and the overall spatial arrangement in ordinary Kriging (Environmental Systems Research Institute, 2016).

Then, we extracted cellular phone network data from the API Open Platform Thermodynamic Diagram, calculated the urban population density, and detected hotspot patterns on the basis of the record on a representative workday.

$$P(j) = \sum_{i=1}^{n} S(ni) \times P(i),$$

where $P(j)$ is the active population in each pattern, $P(i)$ is the active population represented by ith category in the thermodynamic diagram, S(ni) is the area size of the ith category, and n is the number of categories (Tan et al., 2016).

Meanwhile, we calculated the urban morphological density and detected hotspot patterns with urban footprint data published by the Macau Cartography and Cadastre Bureau (Macau Cartography and Cadastre Bureau, 2020).

$$B(i) = \frac{M(i)}{A(i)},$$

where, $B(i)$ is the urban morphological density, $M(i)$ is the urban footprint, and $A(i)$ is the size of a hotspot pattern.

Finally, using bipolar coordinates, we applied visual analytics that is widely used in environmental studies (Maciejewski et al., 2010; Li et al., 2016). We generated a set of interrelated thematic maps to understand the spatiotemporal hotspots and detect the spatial congruency or mismatch relationship between COVID-19 potential risk and urban density.

3. Spatial relationship between COVID-19 risk and urban density

We identified 22,087 reopening business locations across the entire Macau Peninsula hosting 36 daily activities in GIS. Figure 2(a) is generated from Surfer, and the surface shows the potential risk of different levels ranging from low (0) to high (10). Figures 2(b) and (c) show urban density, including population density with hotspot patterns ranging from 20,000 to 50,000 per square kilometer and morphological density with hotspot patterns ranging from 500 to 1000 per kilometer, respectively.

Through visual analytics, we found that the high-risk peaks (risk levels 8–10) neither intersect with high population density nor with high morphological density. This finding indicates that spatial mismatch exists between urban density and high-risk peak on the basis of the POI distribution. By contrast, the risk peaks with medium degrees (risk levels 4 –5) intersect with some of the hotspots with high population density. This finding further suggests that

as businesses reopen, contagious transmission from person to person, once infected, is fast due to the high density and population mobility in these hotspot areas despite a short face-to-face exposure time. Similarly, while risk peaks with low–medium degrees (risk levels 2–3) intersect with some hotspots of high morphological density, the high- and medium-risk peaks are not congruent with morphological density hotspots.

The results could be explained by the fact that businesses with high respiratory disease infection risk frequently host large crowds in a closed space unit and physically lack social distancing measures, such as casinos, concerts, bars, and churches. The locations of these businesses are driven by the market regardless of their surrounding land uses and are not typically located in areas of high morphological density. Furthermore, precautionary behaviors during the pandemic might prevent people from going to locations with highly susceptible infection risk (Hamidi et al., 2020; Thoma et al., 2021), which can explain the observed mismatch relationship between potential risk peak and urban population density. The above explanations together elaborate why the POI-based business spatial distributions and locations determining levels of potential infection risk are somehow mismatched with urban density characteristics.
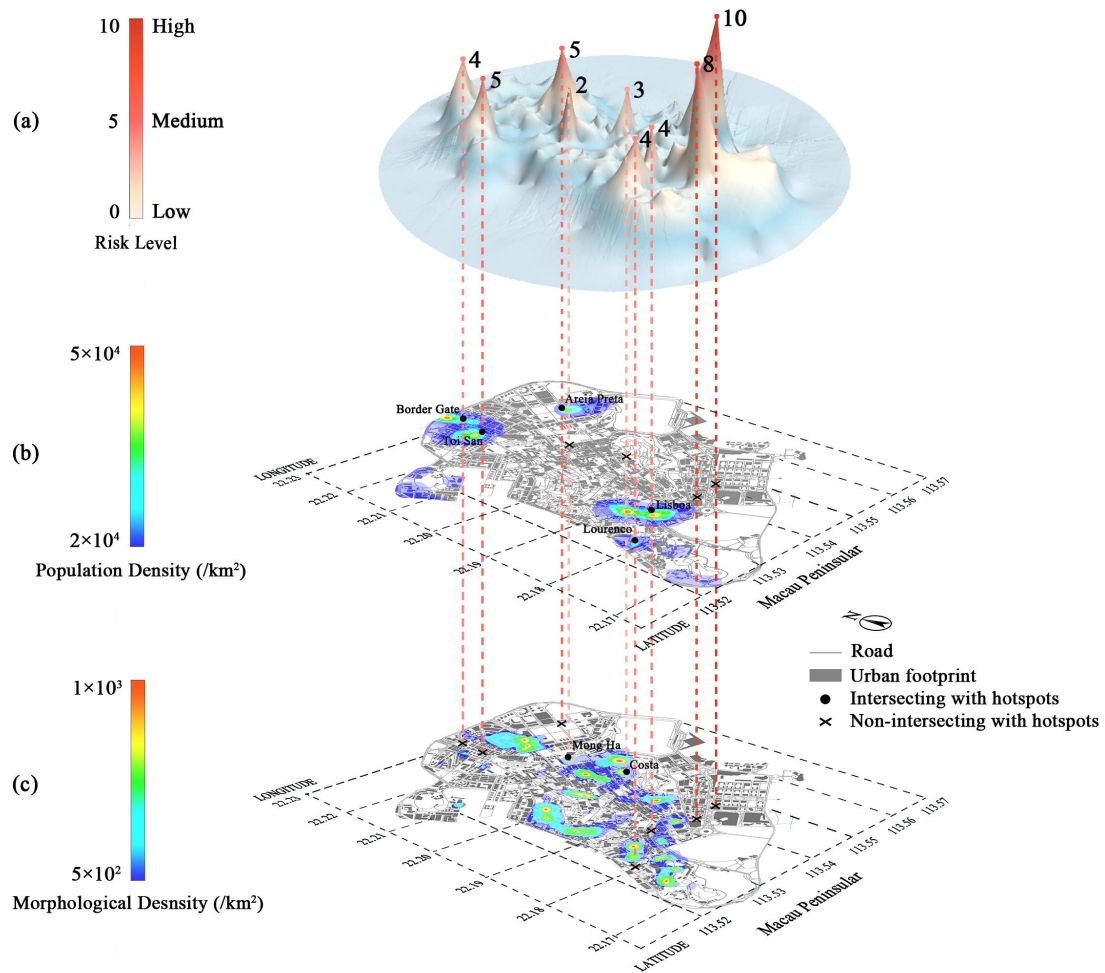
Fig. 2 COVID-19 potential risk peaks as businesses reopen and urban density in the Macau Peninsula.

Notably, the method used in this study can be applied in other localities attributed to the fact that up-to-date POI data extracted by natural language process (NLP), urban density relevant data retrieved from planning departments, and real-time population density data provided by location-based services (LBS) are becoming increasingly available for research purpose in some other cities and regions across the world (Arribas-Bel and Bakens, 2018; Zhai et al., 2019). This transferrable analysis can be used by policy-makers to effectively investigate the potential infection risk of COVID-19 spatially and its correlation with urban density, thereby revising existing pandemic control policies to mitigate the potential risk of COVID-19. Additionally, the Surfer model is affordable and accessible in over 190 countries (Golden Software, 2022) and yields lucid analysis results and

explicit visualization graphics in ways both the policy-makers and the public can understand directly and take prevention measures accordingly.

4. Conclusion

With the latest POI, mobile phone cellular network, and high-resolution spatial data, this study provides a quick measure of the potential COVID-19 risk to the public in an urban environment from the perspective of business reopening and its spatial congruency or mismatch relationship with urban density. This study is important given the controversial conclusions regarding urban density and virus spread (Hamidi et al., 2020; Seidlein et al., 2021; Shen, 2021). Lifting lockdown restrictions and reopening businesses hastily along with growing public concerns about the pandemic may trigger new concerns, especially when the healthcare system burden remains high around the world (NHS Confederation, 2021; Lawless, 2021).

Our analysis suggests that higher urban density is not necessarily concordant with higher COVID-19 risk when the spatial distributions and locations of businesses for daily activities are considered. The POI-based estimation is a decent method to evaluate the spatial heterogeneity for potential risks as businesses reopen. Apart from the knowledge of confirmed infection status, which is normally a concern for lifting restrictions in Asia Pacific and Europe (Han et al., 2020), decision-makers are also suggested to weigh spatial peaks of potential risk and their distribution patterns to lift restriction plans safely in smart ways with priorities and phases to prevent new possible waves of COVID-19 transmission given the fact that new variants are circulating.

This study is informative for urban planners and policy-makers by providing insights on how a specific and detailed built environment with good data is linked to a pandemic. The urban morphological density has been used as a tool in zoning in planning practice to manage development in different urban functional areas for over a century. However, this study indicates that it cannot reflect the potential risk levels and is no longer adequate to cope with potential uncertainties, especially for great pandemics such as COVID-19. Thanks to recent geoscience and big data technology, POI data could facilitate a straightforward and effective alternative to urban morphology regulations with crude data. Therefore, a POI-based spatial distribution and location policy that precisely reflects the characteristics of businesses for

daily activities and risk levels is recommended in planning more resilient cities and communities.

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