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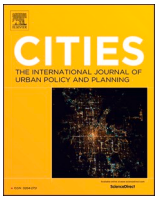

Measuring social resilience in cities: An exploratory spatio-temporal analysis of activity routines in urban spaces during Covid-19

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ABSTRACT

Covid-19 has dramatically changed life in cities across the globe. What remains uncertain is how national policies and appeals to comply with suggested rules translate to changes in the behaviour of citizens in urban areas. This lack of local knowledge leaves urban policy makers and planners with few clues as to the determinants of social resilience in cities during protracted crises like a pandemic. Methods are required to measure the capacity of people to conduct routine activities without risking exposure to a prevalent disease, particularly for those most vulnerable during a health crisis. By spanning the fields of urban resilience, human geography, mobility studies and the behavioural sciences, this study explores how to measure social resilience in cities during a protracted crisis. Using a public participation GIS online platform, we observe changes in citizen behaviour within urban spaces during the Covid-19 pandemic. Inhabitants from three districts of a Dutch city mapped their activity routines during the lockdown period and during the year before the pandemic. Spatio-temporal analysis reveals changes in the clustering of activities into what we describe as 'activity bubbles'. We reflect on the influence of the urban space on these changes and assess the contribution of this exploratory research methodology for gaining insights into behavioural change. Implications for urban planning and resilience theory are discussed.

1. Introduction

Our highly connected cities and urban regions are becoming hotspots for protracted crises like pandemics. UN Secretary General António Guterres labeled cities 'ground zero' for Covid-19, with 90 % of early cases reported in urban areas (Guterres, 2020). Increasing pandemic preparedness in cities is urgently needed to reduce disaster risk. Urban areas consist disproportionately of people living in high-density housing areas, immigrant neighborhoods and low-income communities. Such populations are acutely impacted by chronic stresses such as exposure to pollutants and disease and inadequate access to basic services and amenities (Sharifi & Khavarian-Garmsir, 2020). Oftentimes, these marginalized populations bear the greatest burdens to ensure the resilience of a city (Doorn, 2017). The pandemic has exacerbated these existing vulnerabilities and inequalities. Many low-wage workers who are unable to work remotely rely on public amenities and services in crowded urban spaces, and as a result, are less capable of mitigating their risk of infection (Florida, Rodríguez-Pose, & Storper, 2021; Robinson et al., 2020).

The highly contagious nature of the coronavirus has prompted governments to combine their vaccination programs with non-pharmaceutical interventions (NPIs) ranging from social distancing and increased hygiene to curfews and lockdowns. The World Health Organization stressed the importance of coordinating these mitigation measures during the Omicron variant outbreak (World Health Organization, 2021). But the effectiveness of measures relies heavily on persistent change in behaviour towards compliance with NPIs to contain disease spread (Eaton & Kalichman, 2020). In the likelihood that the Covid-19 pandemic becomes endemic (Phillips, 2021), reliance on NPIs for public health purposes may remain a necessary part of Covid-19 mitigation strategies in the coming years. Vaccine hesitancy, inequity in the global distribution of vaccines, and the risk of new variants of concern point to behaviour-based mitigation practices as a primary line of defense.

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The ability to leverage social capital through collective action in following recommended NPIs is a crucial part of Covid-19 mitigation strategies in many European countries (Bartscher, Seitz, Siegloch, Slotwinski, & Wehrhöfer, 2021). What remains uncertain is how appeals to comply with national NPIs translate to desired change in the behaviour of citizens locally, as multiple factors influence the effectiveness of NPIs (Sharma et al., 2021). One white spot in research literature is how adaptive behaviour is enabled or constrained by urban spaces and their features, and how both, in turn, impact the ability to engage in interactions that increase social capital during a pandemic. Despite the surge of publications and policies related to urban resilience (Meerow, Newell, & Stults, 2016), recent reviews show major knowledge gaps in the measure of societal and health-related risks, particularly during pandemics (Biddle, Wahedi, & Bozorgmehr, 2020; Sharifi & Khavarian-Garmsir, 2020). Resilience studies often focus on (rapid) recovery from a single shock event such as a flood or earthquake. But Covid-19 presents a protracted crisis that unfolds over an extended period of time and overlaps with heatwaves, floods, earthquakes and other acute shocks. The resulting compounding effect has put large portions of the population at risk and made the trajectory of the pandemic highly dynamic and uncertain.

Numerous data collection efforts have been conducted to understand the impact of the Covid-19 pandemic from a behavioural change perspective. Yet, the majority of studies focuses on the national or regional level (e.g. (Ferguson et al., 2020; McGrail, Dai, McAndrews, & Kalluri, 2020)). Mobility data has been used to track contact networks and epidemic spread locally (Chang et al., 2020; Schlosser et al., 2020). Time-geographic approaches using mobile phone network data to analyze activities during the pandemic have shown new organizations of spatial behaviour (Toger, Kourtit, Nijkamp, & Östh, 2021). Using mobility data to detect hotspots and the emergence of new behaviour trends, however, often misses an important link between the movement patterns – e.g. expressed by the origins and destinations of trips – and factors influencing the choice of where to travel. Besides that, the use of highly granular mobility data is questionable from the privacy standpoint and therefore not widely adopted across European countries. What we currently lack from a methodological standpoint, is a resilience framework to study the interplay between human adaptive behaviour and the urban environment during protracted crises. Knowledge about this interplay is needed to formulate NPIs that will garner broad public acceptance and compliance for the extent of the crisis.

We argue for a participatory approach that invites citizens to co-create this novel understanding of their adaptive capacity within a local urban area. Measures to mitigate disease spread such as lockdowns have been coordinated at the national level with limited citizen participation in the Netherlands. But, a participatory value evaluation survey conducted with 30,000 citizens concluded that the majority of Dutch adults oppose the government's lockdown measures even under high-risk conditions (Mouter, Hernandez, & Itten, 2021). The present study aims to give local communities a voice in designing policies that are socially acceptable and situated in the local context with the aim of enhancing compliance with NPIs. Sub-city geographical subdivisions have been used as units of analysis to understand how parts of the city are affected by the coronavirus differently (Khavarian-Garmsir, Sharifi, & Moradpour, 2021). Still, there is a paucity of research on how NPIs and other drivers impact local activity routines. Our contribution to existing literature concerned with the measurement and evaluation of social resilience is to explore how to measure social resilience in cities for protracted crises using spatio-temporal data contributed by citizen participants.

The paper proceeds with a review of relevant literature on urban space and social capital as they relate to social resilience and the implications of protracted and dynamically evolving crises such as Covid-19, in a departure from conventional understandings of resilience to a sudden shock. Thereafter, the research methodology is described, which includes the creation of *district profiles* for the three case districts, a description of the applied spatio-temporal behavioural surveying technique for data collection, and the data analysis method. We then examine the routines that people regularly follow, and identify *activity bubbles* in which citizens move and observe how they changed during the pandemic. Using comparative analysis of the three case districts, factors relating to socio-demographic characteristics and features of the urban space are taken into account. We discuss potential implications of the findings with respect to national responses to pandemics, on long-term implications for the planning and design of cities and on theoretical insights gained into social resilience during protracted crises in urban contexts.

2. Conceptualizing social resilience in cities

The concept of resilience is embedded in various disciplines ranging from ecology, engineering and disaster management, to psychology and the behavioural sciences. All disciplines apply nuanced definitions of resilience while sharing a framework for thinking about sustainable futures for systems under conditions of increased uncertainty and risk (Mitchell & Harris, 2012). Resilience thinking has inherited a rich vocabulary from these disciplines to describe how systems respond to disturbances (Davoudi, Brooks, & Mehmood, 2013). Engineering resilience describes the capability of a system to *bounce back* to its equilibrium state. Ecological resilience introduces the notion of adapting to a new state of equilibrium or a *new normal* after a disturbance. Social resilience concerns the ability of social entities (such as groups or communities) to absorb, tolerate, cope with or adjust to external stresses and disturbances (Adger, 2000; Keck & Sakdapolrak, 2013). As such, social resilience concerns the adaptive capacity of people at risk or during a crisis in which their environment has (drastically) changed (Copeland et al., 2020). Gaining insights into human adaptive behaviour in cities and urban areas has become more time critical as rapid urbanization exposes larger numbers of people to more frequent and prolonged urban disaster events (Saja, Goonetilleke, Teo, & Ziyath, 2019).

Various authors have discussed the challenges in measuring (social) resilience (Copeland et al., 2020; Jones, A Constas, Matthews, & Verkaart, 2021; Maguire & Hagan, 2007; Saja et al., 2019). Because of the multi-faceted nature of the concept, a plethora of indicator models has been put forward to measure the different dimensions that enable or hamper a community to respond to a disruptive event. For a review, see (Saja et al., 2019). A challenge in many resilience studies remains the lack of longitudinal data that allows us to understand social resilience over time (Jones et al., 2021). This is especially relevant in protracted crises such as Covid-19 that span longer time periods. Further, indicator models of resilience largely focus on measuring static capacities or abilities, instead of mapping out the behavioural, spatial or temporal dynamics (Cutter, 2016). There are approaches put forward for dynamic indicator models that define proxies or ‘surrogates' to assess the ability and capacity for change and learning (Saja, Teo, Goonetilleke, & Ziyath, 2021). We here focus on approaches that directly measure the change of behaviour over time and space.

The remainder of this section introduces literature about two key determinants of social resilience: urban space and social capital networks. First, we embed the study in the discussion of *pandemic geography* where we argue for the need to enhance our understanding of the role of the urban space in moderating social interactions during a pandemic. Second, we introduce networks of social capital as life lines for local

communities to reduce the severity of a disaster and to accelerate recovery (Norris, Stevens, Pfefferbaum, Wyche, & Pfefferbaum, 2008; Saja et al., 2019).

2.1. Social resilience & urban space

Social resilience scholars advocate focusing on well-being to measure resilience (Jones et al., 2021). During a pandemic, however, social resilience can entail a trade-off between health and well-being. Access to amenities and services can serve as a spatial proxy indicator of well-being (Biloria, Reddy, Fatimah, & Mehta, 2020; Ettema & Schekkerman, 2016). But, using shared amenities during a pandemic risks exposure to disease (proxy indicator of health) by bringing people into close proximity to one another. People may value maintaining social connections by engaging in social networks within physical spaces despite the associated health risk. Such engagement can have secondary positive benefits on well-being such as avoiding loneliness. Engagement in networks that bridge local and remote communities is further considered to enhance responses to an immediate crisis and to support long-term risk management and planning (Comes, 2016). We define social resilience during pandemics as the ability and willingness of a community (as an aggregate of individual behaviour) to adapt to adverse conditions in a way that social networks are maintained by engaging in routine activities without risking exposure of oneself or others to a prevalent disease.

Urban space is a determinant of social resilience since it sets the physical boundary conditions for activities to take place. The morphological aspects of these spaces, known as the urban form, include both physical and non-physical features like land use, density, transport infrastructure, building types and the interrelations of these features (Dempsey et al., 2010). Resilient urban forms are spatial patterns and representations of human activities occurring over time and in space that facilitate the adaptation of the urban system (Sharifi, 2019). High-density spaces can improve social resilience by fostering encounters that increase social capital (Sharifi, 2019). Access to services and amenities depends in part on density and how land in an area is arranged. This means the spatial distribution of amenities and socio-demographic characteristics of local and neighboring areas can influence social resilience during a pandemic. In addition to space, time sets constraints that limit access to amenities (Geurs & Van Wee, 2004) The analysis portion of this study builds on Hägerstand's time-space prism (Yu & Shaw, 2008) for analyzing time and space as an integrated system that constrains human activity. During the outbreak of an airborne disease, the unequal spatial distribution of amenities and services is relevant, particularly when mobility is restricted and people are bound to their neighborhood. Starting in early 2020, European cities implemented strict lockdown measures including curfews to lower disease transmission. During lockdown periods, the neighborhood became the primary place to conduct many routine activities. Better health and well-being outcomes during Covid-19 were associated with close proximity to numerous local facilities and public spaces such as parks as well as living in lower-density neighborhoods further from the city center (Mouratidis & Yiannakou, 2022). The use of public spaces for exercise and recreation increased during the pandemic in addition to reliance on slow mobility, i.e. walking and cycling, especially outside city centers (Gehl, 2020).

The abrupt reorganization of human activity triggered by the pandemic has ignited interest in the neighborhood both as a local activity space and as a unit of analysis (Florida et al., 2021; Mouratidis & Yiannakou, 2022). From overcrowding in large population centers to unjust spatial distribution of services across neighborhoods, the pandemic has highlighted failures of the existing urban space and the need to organize city life at a smaller scale (Jabareen & Eizenberg, 2021). Increasingly, researchers and city leaders alike are experimenting with new spatial organization concepts such as the 15-minute city. A critical design principle of the 15-minute city model is the availability of a wide variety of amenities such as schools, work, healthcare facilities, commercial stores and services, leisure and natural areas in close proximity (Pozoukidou & Chatziyiannaki, 2021). As an index, amenities can be reached within a 15-minute walk, which corresponds to 1200 m (Balletto, Ladu, Milesi, & Borruso, 2021). In the context of Dutch cities, amenities further away can be reached within 15 min via public transport or by persons who are able to cycle.

Additional design principles of the 15-minute city are density, diversity and digitalization (Moreno, Allam, Chabaud, Gall, & Pratlong, 2021). During Covid-19 these principles gained new associations with urban health and well-being. A pivot from accessibility-based to proximity-based strategies has unlocked people's access to a wide range of services and amenities in the local area (Pozoukidou & Chatziyiannaki, 2021). Access to amenities in close proximity is increasingly being facilitated during the pandemic by slow mobility with positive benefits for both physical health and well-being. Digitalization has enabled the mass transition to remote work, which is enabling more social distancing and less need to travel for some (Moreno et al., 2021). However, this shift raises new concerns about well-being and health during a pandemic. One concern is the exacerbation of inequalities particularly for vulnerable populations who are less able to adopt these new behaviours like essential workers whose work cannot be conducted remotely. Another concern is how the abrupt change in activity routines to neighborhood-level pockets of activity may actually increase the risk of disease exposure, plausibly resulting in new, localized outbreaks. Thus, NPIs and proximity-based urban planning strategies that would create denser networks of physical social interactions should be considered carefully in terms of increased health risks during a pandemic.

2.2. Social resilience and social capital networks

In a nutshell, social capital stresses that people provide, access, and use resources embedded within their social networks. For an overview of the different definitions, see (Kadushin, 2004). Social capital is associated with stronger networks and access to support systems and resources, and thereby with the ability to more rapidly recover from a shock (Shahid et al., 2022). Not surprisingly, there is a wealth of studies that link social capital with social resilience, e.g. (Aldrich & Meyer, 2015; Nakagawa & Shaw, 2004; Norris et al., 2008; Pfefferbaum, Van Horn, & Pfefferbaum, 2017). Social capital networks provide a setting for interactions and access to support through bonding, bridging or linking (Rutten, Westlund, & Boekema, 2010). Bonding networks convey information and norms within a community while bridging networks connect people of different demographics or across spatial boundaries and are relied on particularly in disastrous situations (Aldrich & Meyer, 2015). Linking networks connect people across power gradients (Boonstra, Claessens, Warsen, & Van Meerkerk, 2022), such as linking support organizations to local activities and initiatives. Given the fast pace at which people self-organize during a crisis, government organizations may be ill-equipped to respond effectively (Boonstra et al., 2022). We claim that studying processes of self-organization can enhance organizational resilience by providing information on how people adapt their activity routines and their resulting interactions.

Social interactions in urban areas are temporally and spatially located (Cox & Perry, 2011; Norris et al., 2008). Proximity in space has been shown to foster connections, inspiring communities and people to help each other and thereby foster their capacity to respond (Jamshed,

Birkmann, Rana, & Feldmeyer, 2020). Recent studies show that areas with high social capital during Covid-19 experienced slower increases in cases compared to areas with low social capital (Bartscher et al., 2021). Communities with stronger bridging social capital and mobility seemed to have a greater adaptive capacity during Covid-19: a study from 2021 showed that after initial peaks, stronger bridging ties resulted in quicker decreases in infection rates likely due to willingness to adopt new health behaviours (Fraser & Aldrich, 2021). However, the geography of social capital in terms of where and how these networks manifest in space and over time, specifically how and in how far access to urban amenities and services impacts social capital, has received limited attention in the literature (Jones et al., 2021; Rutten et al., 2010). More generally, while features like 'place attachment', social embeddedness and participation are considered a part of social capital in the resilience literature (Norris et al., 2008), little is known about how urban spaces and their features shape participation and interaction over time (Cox & Perry, 2011).

Social capital can be measured in terms of continuous flow or discontinuous flow obstructed by barriers. Geographic, political and socio-demographic barriers each promote bonding and interrupt bridging networks (Westlund, Rutten, & Boekema, 2010). Such barriers can hamper social resilience in the aftermath of an abrupt shock by limiting the ability to connect with others or to access resources in communities outside the hazard area. Mobility and centrality, on the other hand, can foster social resilience. Mobility overcomes barriers by providing access to services and activities while facilitating social networks and stimulating face-to-face contact (Östh, Dolciotti, Reggiani, & Nijkamp, 2018). Persons in more central locations with low travel costs may have high levels of social capital (Patacchini, Picard, & Zenou, 2015).

Pandemics, however, demand a reconsideration of social capital. We extend the concepts of social capital and resilience to a pandemic case, which is a protracted crisis, marked by the sustained duration of the hazardous event and the volatility of a constantly changing situation. In contrast to a crisis triggered by an abrupt shock like a flood or a wildfire, the entire population is at risk while the urban infrastructure remains intact. Here, the disruption is the threat from the virus and the interactions that typically help a person cope during a crisis, may pose a risk. Conventional thought on the role of mobility and centrality in fostering social resilience, therefore, may be less straight forward in pandemic situations when exposure to others, especially crowds, poses risk of infection (cf. Mouratidis & Yiannakou, 2022).

Until now, the relationship between social resilience during a pandemic and adaptive behaviour in urban space has not been examined thoroughly. Yet, our ability to study this relationship is unprecedented. Scientists now use big spatial data to follow the spread of the worst airborne virus in a century and its impact on highly-connected cities worldwide (Florida et al., 2021). This emerging field of *pandemic geography (*Florida et al., 2021) is offering new insights into the societal effects of pandemics with a finer spatial granularity. Data collection using web-based surveys is being combined with proximity analysis to study access to services and amenities during the pandemic. Participatory mapping results, for example, depict Bogot'a as a segregated 15-minute city where lockdown measures pose a greater risk to low-income people with poor access to centrally located amenities and more dependence on work outside their home (Guzman, Arellana, Oviedo, & Aristizábal, 2021). In a similar vein, we focus on the individual to gain empirical insights into how people self-organized within the constraints of their local urban space during the pandemic. Understanding the emergence of individual, self-organizing behaviour can help formal organizations to develop crisis management approaches that are more inclusive and resilient (Boersma et al., 2022).

3. Methodology

3.1. Research perspective and resilience framework

In this paper we study changes in local networks of activity in urban space reported by individuals during a pandemic as a starting point to measure resilience during protracted crises. Such new participatory approaches to quantify dynamic properties before, during and after a disaster are needed to inform resilience-enhancing actions (Saja et al., 2019).We use an exploratory method for collecting and analyzing data on human adaptive behaviour while seeking access to services and amenities. In doing so, this work follows the call for studies that measure health and well-being during later Covid-19 waves (Mouratidis & Yiannakou, 2022). We are especially interested in the interplay between social resilience and the spatio-temporal factors that influence how people adapt their activity routines within a given urban space, leading to two questions: First, what are the observed changes in the temporal patterns of reported activity routines before the pandemic and during the third wave of the Covid-19 pandemic? Second, what changes do we see in these activity routines when viewed spatially? Cross-district comparison is used to study how social capital networks are potentially constrained or enabled during the pandemic by barriers like administrative boundaries, unequal access to amenities and mobility limitations resulting from lockdown measures.

We explore behavioural change through the lens of social resilience to determine whether activity routines have bounced back or have adapted to a new normal. We express the spatial and temporal dimensions of activities and interactions in terms of localized pockets or *activity bubbles*. We choose the term activity bubble in analogy to Eli Pariser's filter bubble concept for the digital space (Pariser, 2011), whereby the limited interaction with the 'other' reduces diversity. Similar results have been found in crisis response, where 'coordination bubbles' have been introduced to describe localized and fragmented pockets (Comes, Van de Walle, & Van Wassenhove, 2020). As (response) diversity and connections are central to social resilience in cities (McPhearson, Andersson, Elmqvist, & Frantzeskaki, 2015), it follows that shrinking activity bubbles reduce social capital and thereby resilience. We propose that the physical features and socio-demographic characteristics of an urban space may influence this relationship.

Herein, social capital theory frames our examination of activity routines using two perspectives:

- Structuralist perspective: physical features of an urban space and socio-demographic characteristics either enable or constrain the activity routines of residents and visitors to the area. These features and characteristics are summarized in the district profiles.
- Interactionist perspective: networks of physical interaction are created as people engage in routine activities in space and time to access services and amenities. Insights into these networks are gained by analyzing self-reported activity routines.

The three-layer conceptual framework (Fig. 1) communicates the theories underpinning this study for measuring social resilience in cities during a pandemic. The variables of structuralist social capital (layer 1), namely physical features of urban space and socio-demographic characteristics, set the boundary conditions for the formation of physical social networks by enabling or constraining activities, i.e. interactionist social capital (layer 2). We measure at this layer the changes in activity bubbles, or aggregates of individual reported activity routines in time and space. We draw conclusions about social resilience (layer 3) based on these measurements. Here, access to amenities and exposure to disease serve as proxy indicators of well-being and health, respectively. Thus, we hypothesize that engagement in activity routines in time and space entails a trade-off where seeking access to amenities to ensure well-being risks exposure to disease, and thereby one's physical health.

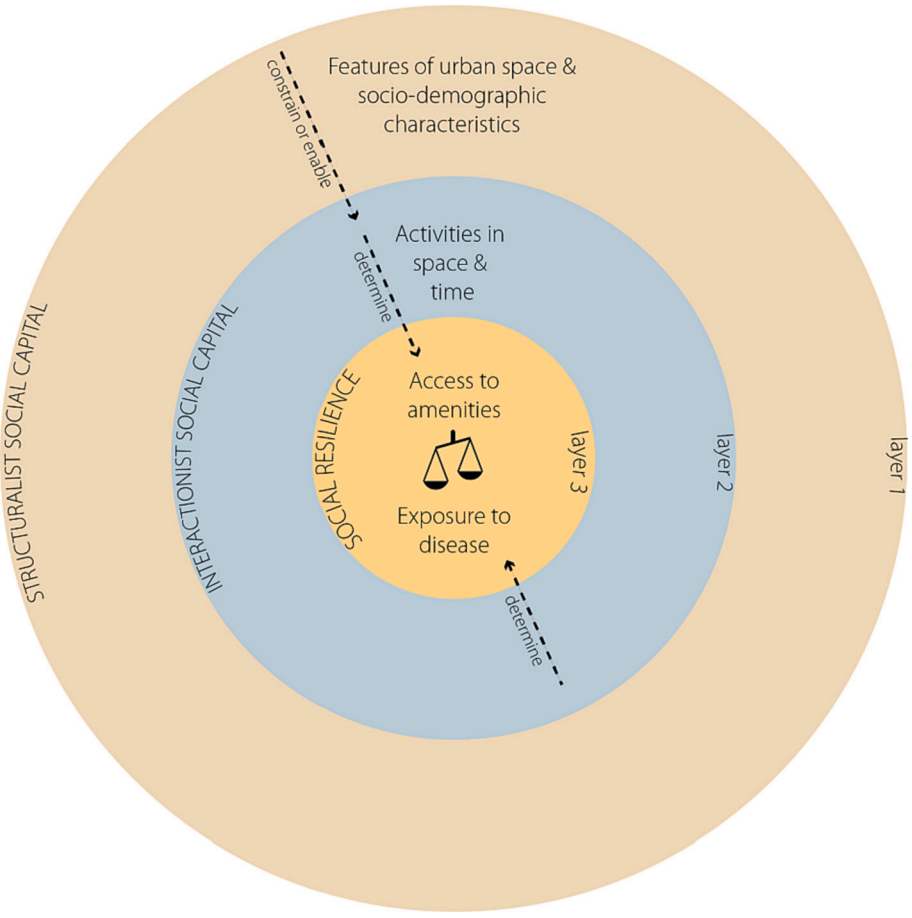

Fig. 1. 3-Layer conceptual framework depicting key theoretical concepts (in all caps) and their operationalization.

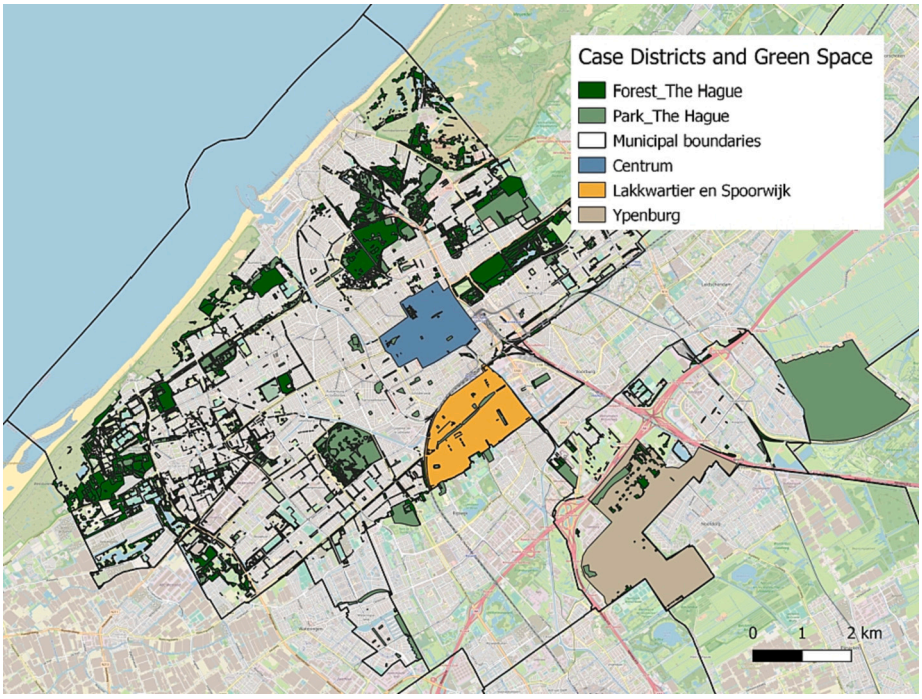

Fig. 2. Study area and three case districts in the city of The Hague, the Netherlands.

Table 1
District Profiles. Features of the urban space and amenities of the three case districts and socio-demographic statistics for the sample ($n = 649$).

Indicator		Centrum	Laakkwartier en Spoorwijk	Ypenburg
Features of the urban space:				
Residents		20,366	43,629	27,059
Children (12 and under)		1,648	5,541	4,036
Gross density (resident/ha)		104.0	163.6	61.2
Green space (ha)		7.9	21.2	34.1
Amenities:				
*Residents (*children) per unit*	Office	39	408	1289
	Daily store	152	464	2081
	*Primary school	412	554	505
	*After school care	330	504	269
	Playground	5092	4847	2706
	Sports facility	1567	3636	3866
Sources: Den Haag in Cijfers (yr. 2021) and QuickOSM a. PDOK				
Socio-demographic characteristics:				
Age group (%)				
	<30	29	42	14
	30–50	30	27	40
	>50	41	31	46
Household size (%)				
	1–2	73	52	29
	3–4	22	38	60
	5–10	5	9	11
Education level (%)	Primary and secondary	8	18	13
	Mid-professional	53	60	64
	Higher education	39	23	23
Income group (%)				
	<30,000	45	58	10
	30,000-58,500	31	33	41
	>58,500	24	10	49

Source: Survey respondents.

3.2. Case study context: three districts in The Hague

Data collection was conducted in the city of The Hague, the Netherlands. The Hague is a coastal city in the Netherlands with 549,163 residents. The Hague is one of two major cities in a large metropolitan region with a total population of approximately 2,7 million people. More than half of citizens in The Hague (56,2 %) have a migrant background (The Municipality of The Hague, 2022). While the average disposable income per household in 2018 was 40,600 EUR, almost half of its population was classified as low income. The Hague has a relatively young population with 85,9 % of the population below the age of 65 compared to 80 % nationwide (Statistics Netherlands, 2022). The Hague is divided into 44 municipal districts (*wijken*).[1] For this study, the municipal districts Centrum, Ypenburg and Laakkwartier en Spoorwijk were selected (Fig. 2).

District profiles (Table 1) provide an overview of the socio-demographic characteristics and features of the urban space for each district (see Fig. 1, layer 1). The district profiles borrow from urban profiling as a method to synthesize information about a (part of a) city from existing sources supplemented by field research (UN-Habitat, 2021). Descriptive statistics about features of the urban space (residents, density, green space and amenities) were retrieved from open access datasets published by the Municipality of The Hague (https://denhaag.incijfers.nl/) and the QuickOSM plugin for QGIS. The amenities included in the district profiles are office spaces, stores for daily shopping, primary schools, after school care locations, playgrounds and sports facilities. Displaying the amenities by number of residents per amenity unit provides a quick overview of the distribution of these amenities in each neighborhood. The socio-demographic statistics were collected from respondents to our survey. Note that the socio-demographics characteristics of those who reported their activity routines vary from open source statistics published by the municipality, see Table 5 in Appendix A.

Centrum is classified by the municipality as a 'very strongly urban' district. This high-density district has comparatively little green space but the most stores for daily shopping and >2,5 times more commercial offices than any other district in the city. The residents of Centrum are characterized as highly educated with a distributed average income, living in small households with few children. Laakkwartier en Spoorwijk has almost three times more green space and more than twice the population of Centrum. The district has the largest number of residents 12 years and younger, resulting in relatively full primary schools and after school care facilities. Survey respondents in the district were comparatively young, living in larger average household sizes with the lowest income and education levels of the three districts. The district consists of a large number of shops and sports facilities that cater to its diverse population. Ypenburg is located opposite a large highway from the other two districts and has a lower density classification of 'strongly urban'. Its residents are predominantly mid- and high income, with many family-sized households and education levels similar to that within Laakkwartier en Spoorwijk. The district has very few office spaces (21) and stores for daily shopping (13) registered with the municipality, cf. 107 and 94 respectively for Laakkwartier en Spoorwijk.

The features of the urban space and socio-demographics for the three districts can be summarized from a structuralist perspective as follows: Centrum has a diverse population serviced by a large variety of amenities but lacks green space for outdoor activities; Laakkwartier en Spoorwijk has a large, diverse population serviced by a large variety of amenities in a high-density area but with sufficient green space and Ypenburg has a less diverse, higher income population serviced by only a few shops and offices, but has ample green space for sports and gatherings.

3.3. Survey method

To explore both bonding and bridging network structures, we surveyed residents about their activity routines within and across the boundaries of their home district using a map-based survey. The survey was hosted on the Maptionnaire (maptionnaire.com) public participation GIS (PPGIS) platform. PPGIS are tools for sourcing spatially explicit, local knowledge directly from individuals (Kahila-Tani, Kyttä, & Geertman, 2019). Map-based surveys belong to participatory mapping methods aimed at eliciting knowledge to create collective representations of reality (Voinov et al., 2018). The survey was distributed over a period of two weeks in early April 2021 during the third wave of Covid-19 infections in the Netherlands. A third-party online marketing firm advertised the survey on the Facebook profiles of residents in the three case districts. The advertisements appeared according to the language setting of the user in either Dutch, Arabic, Turkish or English. The survey was also provided in these four languages, which are most commonly spoken in The Hague. The survey was also advertised in the Ypenburg local paper. The authors shared the survey link in professional channels.

Respondents were asked to map their activity routines for two time periods: for a typical "pre-pandemic" week in 2020 before the first social

[1] Municipal districts are a subclassification of the 8 urban districts (*stadsdelen*) of The Hague.

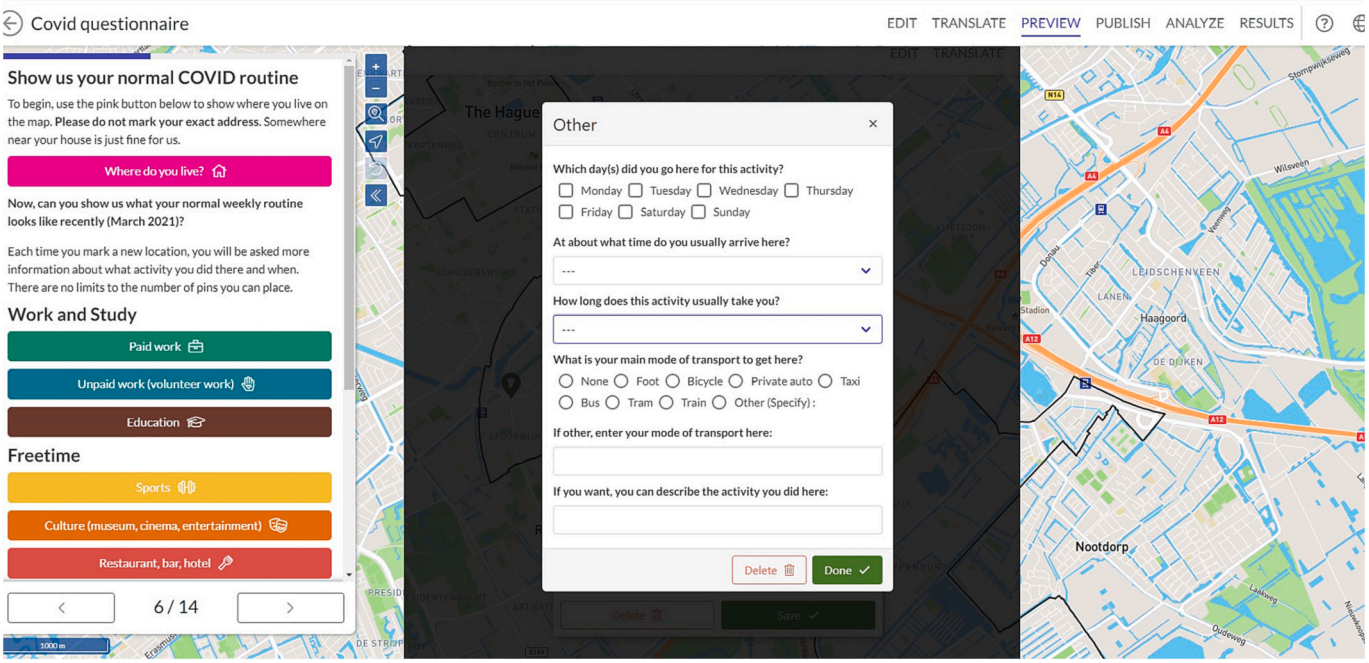

Fig. 3. Activity routine section of the survey showing the during Covid-19 period routine activity options and window with follow-up questions.

distancing and work-from-home advice was announced and for a typical "pandemic" week in 2021 (Fig. 3). After trialing with colleagues, we estimated the time needed for the thorough completion of the survey to be 15 min. To control for potential seasonal differences in activity routines, respondents were asked to map their activities during an average week in March for both years. In the pandemic period, lockdown regulations first implemented on December 14, 2020 were being lifted incrementally. According to the Corona Measures Timeline,[2] the work-from-home advice was in effect and a nationwide curfew was enforced between the hours of 21:00 and 04:30. Primary schools fully reopened in February 2021 and secondary schools followed split schedules to limit group sizes. As of March 3rd, contact occupations including hair salons and massage parlors could accept clients and non-essential stores reopened to a maximum of 2 customers per level on an appointment basis.

The ten (10) activities included in the survey were derived from the national survey "Time Use in the Netherlands" (Roeters, 2017). Activity categories included: paid work, unpaid work, education, sports, culture, restaurant/bar/hotel, care for child or partner, care for elderly, shopping or service and social gathering. Respondents were instructed first to mark a location on the map close their place of residence. For privacy purposes, they were instructed not to mark their exact location of residence. Next, respondents showed us their typical pandemic week by marking where they conduct each activity. A window with follow-up questions appeared for each marked activity on the map. Subsequently, respondents mapped their activities for their typical pre-pandemic week in the same manner on a new map.

Data collection resulted in 27,708 responses from 1077 respondents. We conducted an extensive data preparation procedure before performing the analysis. We started by removing what we call "age outliers": respondents who indicated that they are either too small (e.g. <18) or too large (e.g. 500). Next, we removed "household size outliers": respondents who indicated that their household size is >10. While The Hague is a very diverse city and has large households, unfortunately, in our sample, we did not have enough respondents with a household size ≥ 10. Further, to address "spatial outliers", we selected only those respondents who live in The Hague and activities conducted in the Netherlands. Finally, we removed "temporal outliers": not all respondents indicated when they started the activities and for how long they lasted. After data cleaning, the total number of respondents per district is: Centrum $n = 170$, Laakkwartier en Spoorwijk $N = 231$ and Ypenburg $N = 248$. The average number of reported activities per respondent is 4,84. The median time that respondents spent filling in the survey was 14 min and 31 s.

3.4. Data analysis

Of the ten reported activity categories, we investigate here the following four: paid work, shopping or service, social gathering and sports. These activities are indicative of two essential and two non-essential primary activities during lockdown and have the highest number of responses. To answer the research questions set out in Section 3 concerning changes in activity bubbles, or simply put spatio- temporal changes in localized pockets of activity (see Fig. 1, layer 2), we divide the analysis into two parts.

First, we analyze the temporal element of the survey. Each respondent was asked in the follow-up questions to indicate how often they conduct a certain activity in an average week - *weekly frequency*, when a certain activity is conducted - *timing* and how long it takes - *duration*. An example of a routine activity response is that 'paid work' begins at 09:00, lasts for 8 h, and is conducted from Monday to Friday. We use these three exploratory metrics to demonstrate changes between the two periods compared across the three districts and to look for potential overlaps in activity bubbles where risk of infection may be high. The first metric (weekly frequency) α shows us, for instance, a person might shop less frequently, e.g. three times instead of four. With the second metric (timing) β, we aim to investigate how "an average day in the life" has changed due to the pandemic. For example, have people started to work earlier because they do not need to commute anymore? Or maybe some have started to do sports more during the day? The third metric (duration) γ shows us how much time citizens have spent on their routine activities. For example, people spend less time engaging in an activity to avoid exposure or have more time to spend on an activity due to less time spent commuting. We calculate the first metric by averaging the number of respondents who indicated that they engage in a certain

[2] see (Reep & Hupkens, 2021)

activity over any weekday. Then we take the difference between the two time periods and convert it into a percentage. β indicates when district residents were busy with one of the 4 activities on an average day. To compute this metric, we sum vectors of responses δ_j of all residents $j \in [1, N]$ living in one of three districts and divide it by the total number of residents N. Each of the vectors δ_j has 24 elements equal to the number of hours in a day. The elements of the vector are simply 1 if a resident did this activity at a given hour and 0 otherwise. The resulting formula equates to:

$$\beta = \frac{1}{N}\sum_{j=1}^{N}\delta_j$$

Note that the number of respondents N differs by the district. To come up with an average day, we sum up and average out this metric for five weekdays. We calculate its value for two periods of time: pre-pandemic and pandemic. For the third metric, it is helpful to report the average value - duration γ and other descriptive statistics. We calculate γ similarly to β, but we analyze duration by activity instead of getting individual values for 24 h in a day. Along with the average, we report back standard deviation and quantiles.

Second, to assess the spatial changes between the two time periods across three case districts, we analyze a set of activity origin-destination (OD) points. The first spatial metric δ is the haversine distance between the origin (e.g. respondent's home) and destination (e.g. shopping or service location). Haversine distance is the angular distance between two points on the surface of a sphere (Rouberol, 2022). While the actual travel distance can be higher (taking street networks, travel mode, etc. into account), haversine distance can serve as a proxy to compare changes in distances travelled. Here, we aimed to understand whether travel distance of respondents changed due to Covid-19. The second set of metrics is related to the analysis of the "centrography" or "centrality". By centrality, we mean concentration and dispersion of destination points. We hypothesize that if all trips made by the respondents are mapped, they will form spatial activity bubbles denoted E and that Covid-19 could impact the radius of these bubbles. We define three spatial activity bubbles of 25 % percentile, median and 75 % percentile radius. We calculate the radius by computing a metric (e.g. a median) from the sum of all haversine distances travelled by the residents of a particular district. Further, to simplify the visual representation, we take the centre of each district as the centre for a bubble. Based on both haversine distance and centrality, we evaluate changes in activity bubbles to determine whether the reflect bonding (within district) or bridging (across districts) tendencies.

For the analysis we use R and Python open-source programming languages along with key libraries such as PySAL and GeoPandas (Jordahl et al., 2020; Rey & Anselin, 2007).

4. Findings

4.1. Have activity routines changed temporally?

To understand how the pandemic affected the daily routines of residents in The Hague, we first investigate the temporal dimension of their responses. Findings are presented in the order of the three exploratory metrics introduced in Section 3.4.

Table 2 presents the first metric: weekly frequency, or the number of times a person engages in an activity during the weekdays. In the pre-pandemic period, the residents of Centrum and Laakkwartier en Spoorwijk conducted almost the same number of days of 'paid work' activities, approximately 4. Some residents did it less and more frequently: once a week (18 % and 24 %, respectively) or even seven times a week (5 % and 6 %, respectively). During the pandemic, Ypenburg had the largest decrease in 'paid work' by 12 %. Shopping or service activities showed a decrease in 16 % for Centrum and 18 % for Laakkwartier en Spoorwijk, while for Ypenburg the number remains approximately the same. Respondents living in Centrum indicated that in 2020 they did 'shopping or services' about 3.5 times during the week, and in 2021 this was reduced by >0.5 days. Another remarkable difference is related to 'sports' activities. Frequencies in Centrum and Ypenburg increased by 22 % and 14 % respectively while in Laakkawartier en Spoorwijk, they decreased. In contrast, 'social gatherings' decreased in Centrum and Ypenburg but increased in Laakkwartier en Spoorwijk. The biggest drop of 40 % for Centrum and 20% for Ypenburg indicate that residents of those districts have started to socialize less frequently. These findings indicate that residents have adapted the frequency of most activities to a new normal during the pandemic.

Next, we examine the second metric β: the average weekday temporal activity pattern of a resident. Fig. 4 shows that 'paid work' has bounced back to the same patterns as pre-pandemic. 'paid work' is conducted during the same working hours as before the pandemic. While the frequency of these activities per week remained stable or decreased (see Table 2), the residents managed to get back to a "normal" workday schedule from 9:00 to 17:00. The opposite tendency is observed in 'shopping or services' activities. Here, people have created a new normal. For instance, across all districts people are visiting shops and services earlier, likely to avoid peak business hours and reflecting the earlier closure. Centrum and Ypenburg developed new peak times before the end of the workday and before lunch, respectively.

During the pandemic, 'social gatherings' became "bound" between 08:00 and 22:00 but more dispersed throughout the daytime hours, especially in Ypenburg. One of the explanations for this is the curfew, where citizens (besides essential workers) could incur a fine of 95 EUR if caught outside between 22:00 to 04:30. Given a tighter time limit, citizens tried to fit their needs to socialize into a shorter period - a smaller temporal activity bubble. Centrum residents have started to socialize earlier (before 16:00) compared to a pattern in 2020 that was more dispersed throughout the nighttime hours. Laakkwartier en Spoorwijk got a new peak at 18:00. In contrast, people living in Ypenburg have

Table 2
Weekly frequency α. The colour scheme (gray: similar, blue: decrease, red: increase) helps to highlight the percentage difference between the two time periods.

District	Period	Paid work	Shopping or service	Sports	Social gathering
Centrum	Pre-pandemic, 2020	4.03	3.54	2.53	2.50
	Pandemic, 2021	4.18	2.98	3.08	1.50
	Difference, %	4	-16	22	-40
Laakkwartier en Spoorwijk	Pre-pandemic, 2020	4.20	2.97	2.86	1.73
	Pandemic, 2021	3.91	2.44	2.69	1.88
	Difference, %	-7	-18	-6	9
Ypenburg	Pre-pandemic, 2020	4.44	2.59	2.19	2.00
	Pandemic, 2021	3.92	2.44	2.50	1.60
	Difference, %	-12	-6	14	-20

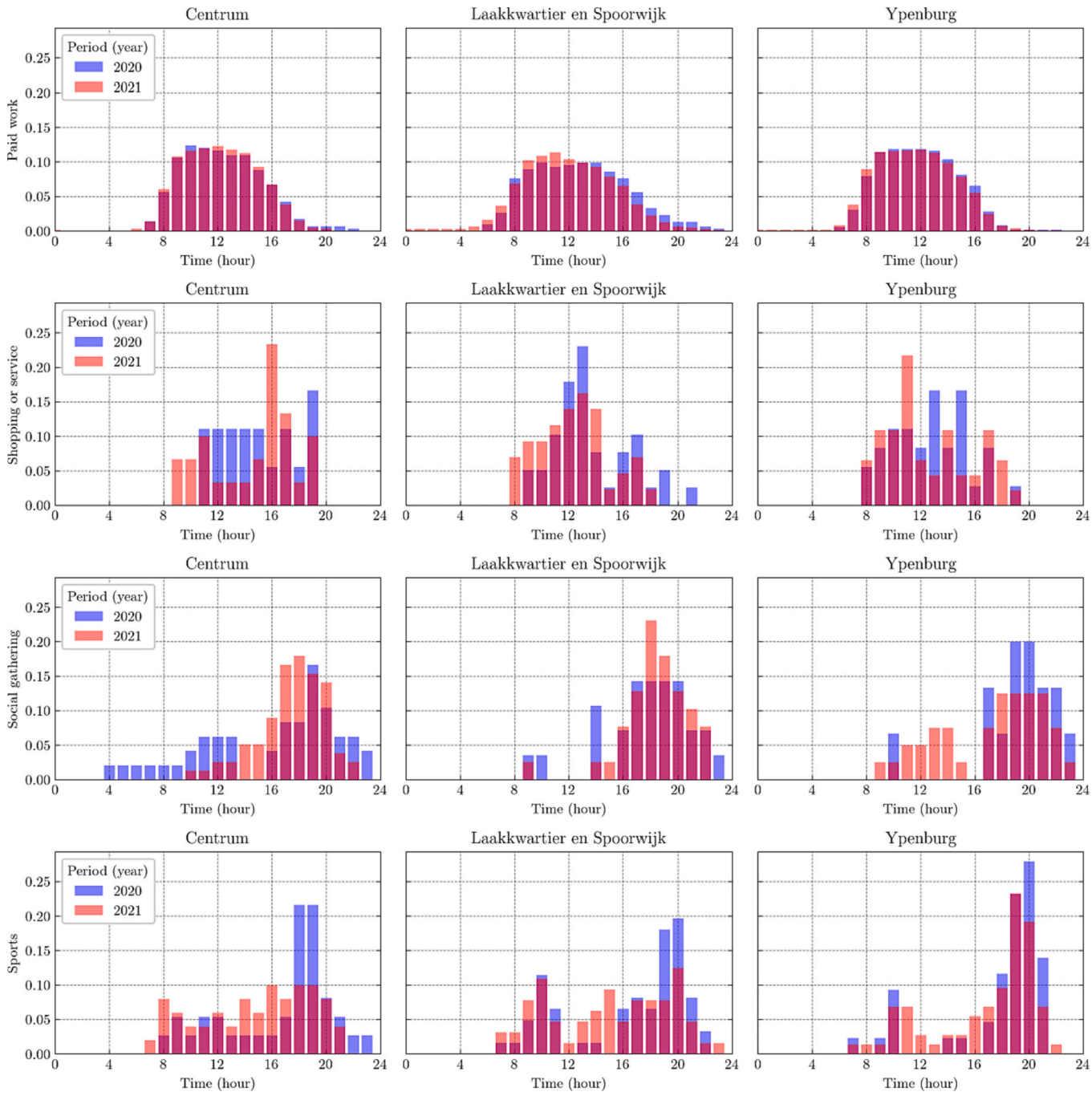

Fig. 4. Average temporal weekday activity pattern - timing β. The x-axis represents time, an hour of the day, and the y-axis shows the % of people doing an activity at the given hour on an average over all week days.

indicated that now they socialize more in the midday (from 11:00 to 14:00). The clearest example of "stretching out" the activity bubble temporally is with 'sports'. Before the pandemic, Centrum had a distinct peak at around 18:00, likely due to people finishing their work and going to exercise. In 2021, residents of Centrum and Laakkwartier en Spoorwijk preferred a more flexible schedule. There is no distinct evening peak anymore. Instead, more evenly distributed times are observed.

Overall, residents of The Hague have bounced back to their pre-pandemic patterns for 'paid work' and (in part) compensated for 'social gatherings' activities by increasing 'sports' routines. Meanwhile, they have adapted their routines in the following ways: multiple "new normal" patterns for 'shopping and services' activities often beginning earlier in the day, 'social gatherings' dispersed but bound to a smaller temporal bubble and 'sports' activities stretched over a wider temporal bubble under the national lockdown measures.

With the last temporal metric γ in Fig. 5, we aim to understand how time spent on different activities has changed. Note that we scaled the y-axis by row: y values for the first row of graphs vary from 0 to 10 h, for the second row from 0 to 2 h and so on. The median duration of 'paid work' has remained almost the same for Centrum and Ypenburg and only slightly changed for Laakkwartier en Spoorwijk: from 8 to 7.6 h. The time spent on 'shopping or service' in 2021 decreased for all three districts (maximum, median and interquartile range). Residents are spending on average 39 min in 2021 compared to 52 min in 2020, and in the case of Centrum and Laakkwartier en Laakkwartier, they are also

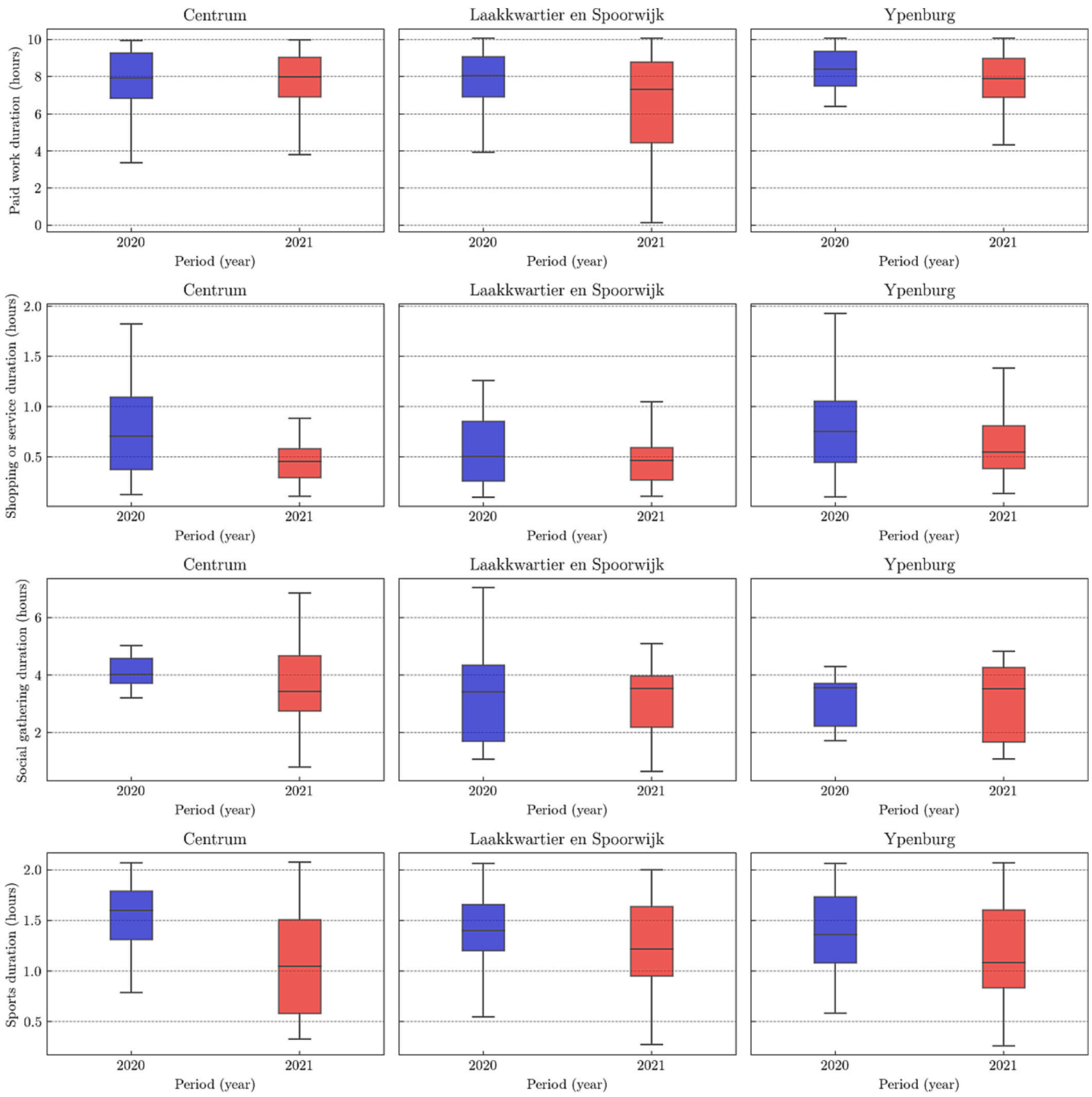

Fig. 5. Activity duration γ. How much time respondents from a district (column) spend on a certain activity (row) on an average over all week days.

Table 3
Trip destinations (%) by spatial scale: its own district (e.g. from Centrum to Centrum), other districts of The Hague and other cities (e.g. Rotterdam), in 2020 and 2021.

		Centrum	Laakkwartier en Spoorwijk	Ypenburg
2020	Own district	49	38	31
	Other districts	37	50	30
	Other cities	14	12	39
2021	Own district	52	45	41
	Other districts	32	32	27
	Other cities	16	23	32

shopping less frequently (see Table 2).

The interquartile range of 'social gathering' increased for Centrum and Ypenburg, but decreased for Laakkwartier en Spoorwijk. Recall that residents of the first two districts have started to meet others less frequently, but sometimes they prefer to have these meetings last longer. The median time decreased only for Centrum from 4.12 h to 3.57. For the other two districts, the change in median between 2020 and 2021 is minor. In the final category of activities 'sports' we see that the median time spent slightly decreased for all three district. People in Centrum reported that they used to do sports for 1.55 h in 2020 and in 2021 this value equals to 1.12 h, in Laakkwartier en Spoorwijk from 1.42 to 1.22 h and in Ypenburg, the smallest change from 1.34 to 1.21 h. There are also increases of the interquartile ranges and minimums and maximums for all three districts. Such changes together with values from Table 2 can

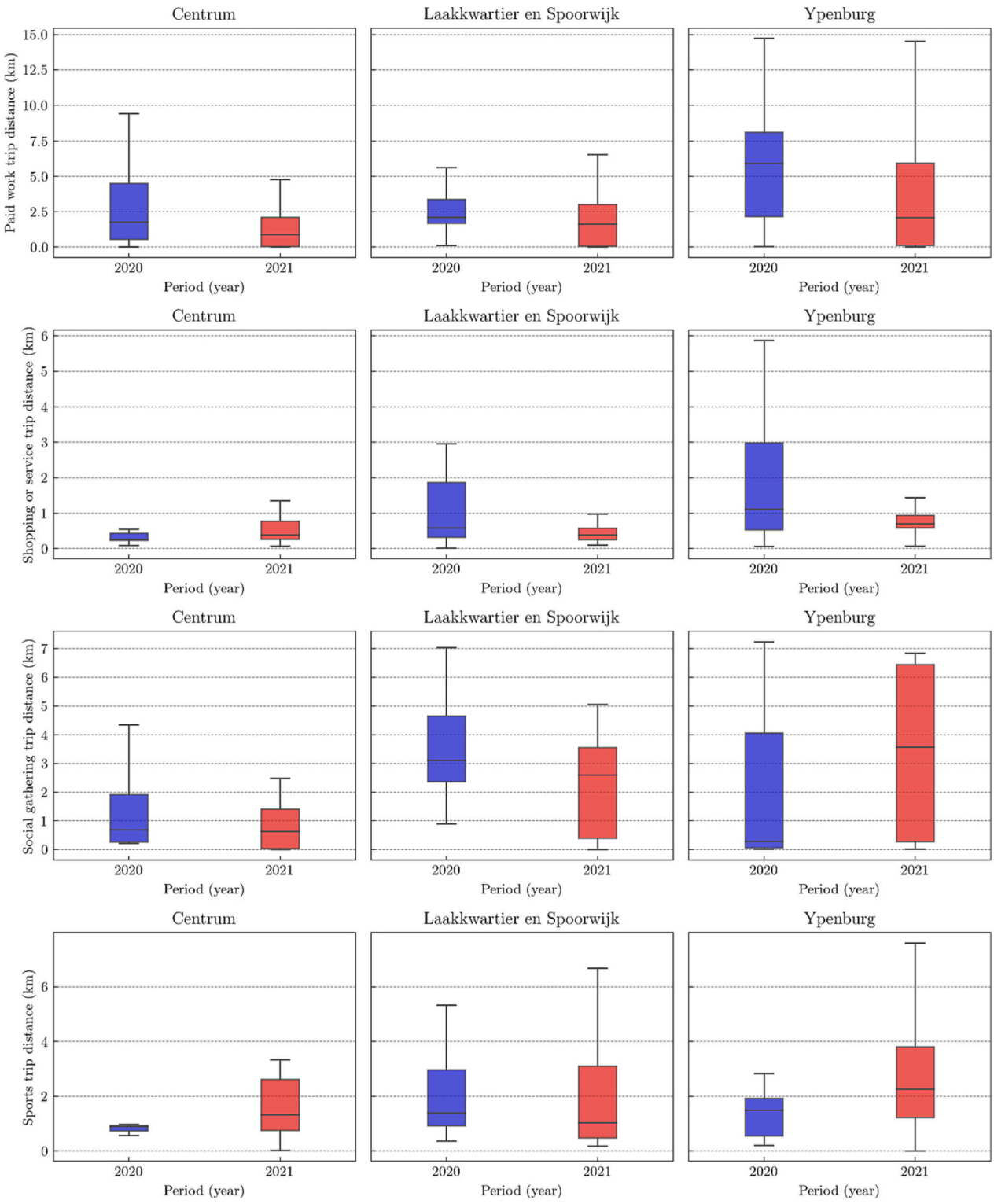

Fig. 6. Travel distances δ. Haversine distances between residents' homes and destinations by activity category. The colour of the boxplots represents the period: pre-pandemic 2020 or pandemic 2021.

indicate that people do sports more frequently but for a shorter period of time.

Temporal findings provide indications of general physical health and well-being in terms of time spent conducting paid work, accessing amenities and engagement in social and sport activities. By combining the temporal findings with spatial analysis, we search for overlaps in time and location of these activities where increased risk of disease exposure may negatively impact health but with potential positive impacts on well-being through social interactions.

4.2. *Have activity routines changed spatially?*

The second part of our analysis dealt with the spatial dimension of responses concerning how the pandemic affected the daily routines of

residents in The Hague. A remarkable finding is the change in the number of trips within and outside the home district. Table 3 shows that in 2020, the percentage of trips by Centrum residents ending in Centrum was 49 %, while for Ypenburg, this number is equal to 31 %. The tendency slightly changed in 2021. Residents of all districts have started to do more activities with destinations in their own districts indicating bonding activities were predominant during the pandemic period. The most remarkable such change occurred in Ypenburg, with an increase of within-district destinations of almost 25 %. At the same time, the number of trips to other districts within the city decreased dramatically

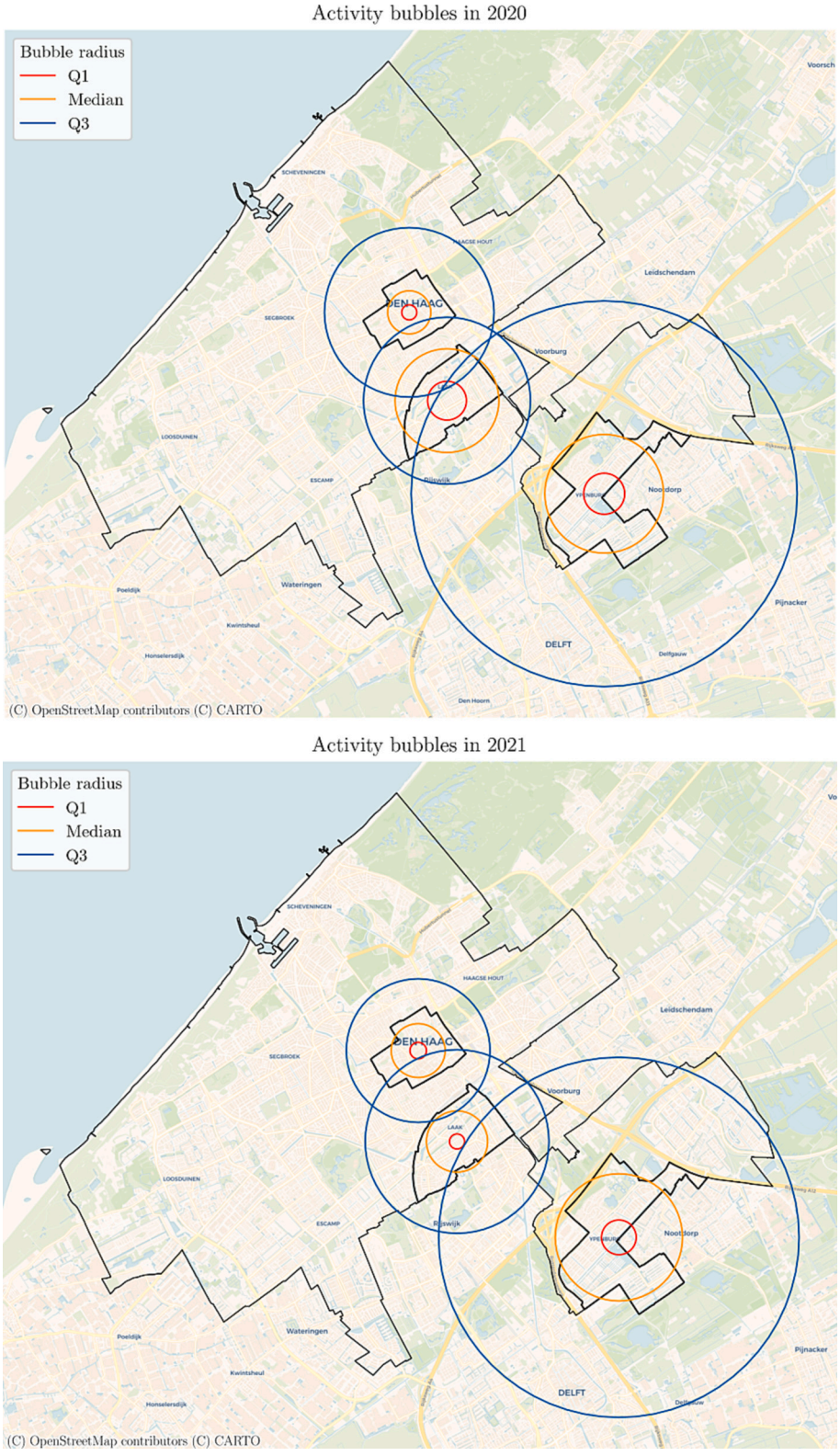

Fig. 7. Spatial activity bubbles *E*. The radius of each bubble is calculated from the travel distances aggregated by category: red - 25 % percentile, orange - median, and blue - 75 % percentile. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

within Laakkwartier en Spoorwijk. Yet, this decrease was partially compensated by an increase of trips to other cities. A possible explanation here is an overall decrease of non-essential trips. In addition to the reduced number of overall trips, and thereby the higher share of work-related travel, we found that the large majority of trips outside the city are related to 'paid work'. These trips were likely essential and could not be replaced by alternative destinations within the city or district.

To further dive into the differences in spatial activity bubbles before and during the lockdown, we analyze the haversine distances from the respondents' homes to the mapped destinations. Fig. 6 consists of 12 subplots: four activity categories (rows) by three districts (columns). Each subplot depicts two boxplots: haversine distances (distances) for 2020 and 2021. Note that we scaled the y-axis by row: y values for the first row of graphs vary from 0 to 15 km, for the second row from 0 to 6 km and so on.

The first row of the plots shows that the median distance for 'paid work' activities decreased for all three districts: from 1.8 to 0.9 km for Centrum, from 2.1 to 1.6 km in Laakkwartier en Spoorwijk and from 5.9 to 2.0 km in Ypenburg. The interquartile along with maximum range for Ypenburg, however, remained relatively large. Some residents of this district still travel to work further away, like in the pre-pandemic year. Another remarkable difference relates to the 'shopping or service' activities. Before the pandemic, the Centrum residents travelled shorter distances than the other two districts. Recall that Centrum has the highest number of daily stores per resident (Table 1). During the pandemic the interquartile range significantly decreased for Laakkwartier en Spoorwijk and Ypenburg, but slightly increased for Centrum.

While the median distance for 'social gathering' remained the same in Centrum and decreased only by 0.5 km in Laakkwartier en Spoorwijk, in Ypenburg, it increased from 0.25 to 3.5 km. In addition, the interquartile range along with the maximum also increased. Thus, the residents of Ypenburg travelled further away for socializing. The residents of the other two districts decided to move these visits closer to their homes. The final category of activities 'sports' shows the opposite trend. The data shows spatial adaptations to Covid-19 and the policy measures across all districts. It is worth noting that since sports centres were closed, people adapted by exercising outside. As we can see from the numbers, these areas are typically further away than in 2020: the interquartile range and the maximum increase for all three districts. Median travel distance for Laakkwartier en Spoorwijk, however, decreased from 1.4 to 1.0 km.

Fig. 7 is a visual representation of a concept that we introduced earlier - the spatial bubble *E*. A bubble indicates an area where a resident travels to access the services of interest, thereby shaping their network of physical interactions, which - in turn - is a determinant of social capital (cf. Section 3.1). Note that here we do not differentiate between the activity categories. We draw bubbles of three radii (25 % (Q1) and 75 % (Q3) percentiles and median) to understand the variance. We can see that the bubble radii vary between the districts and periods. In all cases, we see that the activity bubbles, and thereby interactions become confined to smaller spaces. Centrum residents travelled the smallest distances across the districts in both time periods. Its Q1 (25% percentile, in red in Fig. 7) and median bubbles (orange in Fig. 7) fit the district's boundaries in 2020 and 2021 (see also Table 4). By staying in their district, they have a higher opportunity to bond with other residents.

Table 4
E radius of activity bubbles for the case districts.

		Centrum	Laakkwartier en Spoorwijk	Ypenburg
2020	Q1	0.3	0.7	0.7
	Median	0.8	1.9	2.2
	Q3	3.1	3.0	7.0
2021	Q1	0.3	0.3	0.6
	Median	1.0	1.1	2.2
	Q3	2.5	3.2	6.4

This is likely explained by a high level of structuralist social capital. As highlighted in Table 1, Centrum has by far the highest density of amenities, ranging from stores to offices and schools.

In 2020, Q1 and median for Laakkwartier en Spoorwijk and Ypenburg were almost equal, while Q3 - the people traveling furthest (blue in Fig. 7) - for Ypenburg was significantly higher, largely because of commutes to work. In 2020, the Median and Q3 bubbles for both districts go beyond their district boundary. Therefore, along with an opportunity to bond, they also have an option to bridge and increase the breadth of their interactionist social capital. In 2021, Q1 and median bubbles decreased for Laakkwartier en Spoorwijk, while for Ypenburg Q1 and Q3 decreased. This may further indicate that many of the higher-educated residents of the districts we able to work from home. This reduction in activity ranges left residents with fewer chances to interact with the other districts, indicating a decrease in bridging networks for social capital.

5. Discussion and conclusions

The aim of this study has been to develop a measurement framework to explore urban social resilience in terms of changes in spatio-temporal activity patterns during dynamic and protracted crises like the current pandemic. We have argued for a participatory approach that invites communities to co-create this novel understanding of shifts in their behaviour. The use of a PPGIS survey, enabled us to study changes in activity routines reported by survey participants during a lockdown compared to their routines before the pandemic. National measures to mitigate the spread of Covid-19 in the Netherlands have combined a large-scale vaccination program with non-pharmaceutical interventions (NPIs). Measures including lockdowns, curfews and closure of amenities prompted a mass reorganization of activities in cities. Our analysis of activity routines before and during the third wave of the pandemic reveals the extent of this reorganization of daily life within three districts in The Hague. We especially focus on the influence of urban space on changes in behaviour viewed through the lens of social capital theory.

Findings show that during lockdown people are moving in smaller activity bubbles that are more time bound and spatially fixed within their district of residence. A noteworthy exception is the disappearance of after-work peaks in ''sports activities even though persons who continued to work during the pandemic bounced back to their normal working hours. We additionally find that, likely due to the enforced curfew, people created a new normal by meeting during the daytime with more 'social gatherings' happening midday than in the pre-pandemic period. Activities in all four categories and across districts showed the emergence of a new normal in terms of travel distances and destinations. 'Paid work' was increasingly conducted at or closer to home during the pandemic, while surprisingly, in some cases travel distances to 'social gatherings' and 'sports' increased. This implies that if people were now relatively more confined to their district, they became more reliant on the amenities and resources available in their home and district. At the same time, those who were no longer obliged to commute to work partially compensated their saved travel time by taking further away trips for non-essential activities.

This reorganization of activities raises questions concerning the potential drivers and barriers of urban space, and in turn, what these changes mean in terms of social resilience. Do the case districts have sufficient amenities to accommodate the smaller, more localized activity bubbles and what are the implications of these changes in activity bubbles for public health and well-being? We discuss the findings for each case district based on these questions before reflecting on the main contributions of the study.

5.1. Findings by district

The relatively small activity bubbles for Centrum highlight the importance of urban space to facilitate activities locally: if access to all

essential services and amenities is located within the district, there is little need to bridge across districts, and therefore, little observable change in activity bubbles. According to survey results, trips from neighboring districts to the city center for 'paid work' activities decreased during the pandemic. Looking specifically at 'shopping or service' activities, Centrum residents created a new normal, traveling slightly further than before but engaging in less frequent shopping trips and spacing the timing of their visits over a larger temporal bubble than, for example, in Ypenburg. The district profile of Centrum shows a large provision of essential shopping locations, sports facilities and offices. From a spatio-temporal perspective, Centrum residents may more easily avoid interactions with others, for example, in the emptier locations for 'shopping' or 'paid work' in their district. Additionally, a lack of green space may help to explain the drastic decrease in the frequency of social gatherings despite median trip distances remaining within the 15-minute city threshold for walkability. These findings taken together indicate a trade-off in social resilience that residents in high-density city centers must make. While there are obvious health benefits to the ability to social distance in less crowded indoor spaces, the lack of potential to interact outdoors due to limited green space may have unintended negative impacts on well-being.

In Laakkwartier en Spoorwijk, median travel distances showed that people were able to conduct the largest share of their activities within the district leading to a high potential for bonding. The district profile shows that the district has a large array of amenities including green space that caters to a diverse population. Considering this was the only district that experienced an uptick in social gatherings, the provision of green space may have considerable health and well-being benefits for the residents. However, the relatively low income of residents in the district and nearly constant travel distances for 'paid work' during the pandemic compared to the pre-pandemic period suggest that there may be a large number of essential workers living in the district with less ability to work from home. These findings suggest that the district may have high levels of social capital from both the structuralist and interactionist perspective indicated by their ability to access amenities within a relatively small activity bubble. But, residents of the district may be more vulnerable to infection when engaging in 'paid work' activities outside of the home.

In Ypenburg, the dramatic drops in average distances travelled and Q3 activity bubble radius for 'paid work' and 'shopping' indicate that residents are more reliant on local amenities now than prior to the pandemic. This decrease likely relates to a large portion of the population being able to work remotely. The district, therefore, has experienced a significant uptick in its bonding network, particularly for essential activities since the pandemic. With less need to commute across districts or to other cities for work, the dependence of residents on the small number of local stores for food and personal care increases. Sharp peaks in shopping times like the one observed at 11 am (see Fig. 4) may become a matter of concern for local infections. Furthermore, findings suggest that residents have compensated for their time saved traveling for 'paid work' activities by increasing their travel for non-essential activities like 'social gatherings' and 'sports'. More can be read about this known phenomenon in literature on travel time budgets (Mokhtarian & Chen, 2004). Activity bubbles as aggregates of travel distances may lack the granularity to distinguish this compensating behaviour, which is why comparing across types of activities seems important to understand adaptive behaviour.

5.2. Reflection on methodological contributions

The online map-based survey method applied in this study enables the self-reporting of geo-located activities during a crisis. Repeat calls have been made for more public participation in formulating responses to health crises (Mouter et al., 2021). This participatory approach provides greater agency to citizens in the co-creation of personal data while emphasizing data privacy and measuring behaviour responsibly rather than precisely. In this initial test of the method, we aimed to obtain a 'good enough' result while safeguarding privacy. Our conclusion is that the method enables the co-creation of insights into social resilience at the community level as an aggregate of individual activity patterns within an urban space. We cross-validated our main finding concerning the overall shrinking of activity bubbles with a study that applied a similar PPGIS method. The study observed a similar shrinking that translates into functional segregation, meaning services and amenities concentrated in the city center left residents in peripheral neighborhoods isolated and lacking access to essential services during lockdowns (see (Guzman et al., 2021)). The use of PPGIS methods opens the opportunity in future studies to relate affective factors like lockdown fatigue, fear and risk perception to behavioural change observations.

We contend that our quantitative method for identifying patterns in behavioural change belongs to a mixed methods approach. Next to studying activity bubbles as aggregates of individual behaviours, studies using thick data approaches are needed to understand one-off behaviours (recall Ypenburg's decrease in distances for 'paid work' but drastic increase in distances for 'social gatherings') and to gain access to some of the >1,5 million Dutch adults who are digitally illiterate (Rijksoverheid, 2022). While the graphic user interface of the survey was designed to be user-friendly including tips and comments, we believe that for some of the respondents, this experience was completely new, and therefore, they struggled to navigate it. Here too we are aware that sample populations for the three districts are not representative of official socio-demographic data. Future studies might consider weighting the sample populations or finding ways of increasing the sample size.

We also learned that the ability to recall one's activity routine a month ago far exceeds recall abilities for the same information from a year ago. Less detailed or unfinished reporting of 2020 activity routines led to some difficulty in comparing the two instances. This limitation could be overcome by conducting the survey at multiple intervals, for example, during successive waves of an outbreak. Additional means to incentivize participation in time-intensive surveys like ours seems generally needed given the importance of studying the profound impacts of policies on peoples' lives. Lastly, it was difficult to design a questionnaire for mapping activity routines that include duration, frequency and change over time within the chosen survey tool. Future PPGIS tools could include more advanced functions for generating data in these various temporal metrics and intervals to better support behavioural change research.

5.3. Implications for urban planning

Measuring activity changes in time and space based on the location, frequency, timing, and duration of certain activities has provided us insights into social resilience in cities (see Section 5.1 above). Contrary to studies that have attributed greater adaptive capacity during Covid-19 to communities with stronger bridging social ties and mobility (Fraser & Aldrich, 2021), our findings show an overall shrinking of spatial activity bubbles, limiting the bridging aspects of social capital across districts. This means communities have become more reliant on bonding networks within their local district. But, if we understand social resilience as the ability to adapt to changing circumstances, then our analysis confirms the ability of all case districts to adjust and therefore exhibit resilience. Two examples of how these insights can serve both organizational resilience in crisis response and long-range planning are provided.

First, the observed diversity in resilient behaviour across case districts points to a need for more crisis response diversity and flexibility. Viewing our findings through the lens of social capital theory, we see that social resilience during pandemics in central and high-density districts may be higher than previously thought, in terms of both health and well-being. This can be attributed to the redundancy and diversity of essential services and amenities that under non-pandemic circumstances are accessed by both residents and workers co-occupying central

districts during the daytime. NPIs such as a lockdown have had a dispersing effect on crowds into residential districts. This was evidenced by the drop in bridging activities of residents in Ypenburg and Laakkwartier en Spoorwijk. The health benefits can be measured in lowered risks of infection and rates of disease spread in city centers along with increases in secondary health benefits associated with less traffic, e.g. better air quality and safety. In residential neighborhoods with limited amenities where risk of exposure to disease may be higher, the communication of NPI-compliant behaviour may be a critical part of local pandemic mitigation approaches. Insights into activity routines in real time can be used to steer people away from peak store hours or to direct them to less busy store locations.

Second, through conceptualizing the pandemic as a protracted crises we can consider implications for long-range urban planning. We have seen a trend in the case districts towards bonding activity patterns reflective of the 15-minute city principles: close proximity to a wide variety of amenities, density and digitalization. District profiles in combination with the observed activity routines show us that the distribution of these amenities has an influence on behaviour. More equity in the distribution of amenities across districts is needed, e.g. more stores for daily shopping in peripheral residential districts and more green space for outdoor sports and social gatherings in the city center. Functional flexibility, like we have seen in the integration of work, living and leisure functions within our homes during lockdown, is also required at the neighborhood level (Alraouf, 2021). The design of urban spaces and policies that promote social capital locally can be supported through investments in equal access to shared resources. Connectivity to open streets and spaces, nature and a large variety of amenities can been viewed as vital investments in the future health and well-being of communities rather than a luxury, ushering a return to an *old normal* built on principles of health, ecological sustainability and justice (Alraouf, 2021). As a cautionary note, we found that substantial reductions in travel times for essential activities like 'paid work' likely freed up more time to travel for non-essential activities. This finding serves as a reminder that transitions to a 15-minute city, perhaps accelerated by the pandemic, must be carried out with a deep understanding of citizen behaviours and desires.

5.4. Implications for social resilience in cities

Importantly, compared to conventional resilience metrics that are designed to describe the rapid recovery from a natural hazard, dynamic and protracted crises usher two major changes. First, the notion of assistance by others that are not affected is of limited applicability during a pandemic. The long duration of the pandemic with different waves and peaks has resulted in widespread fatigue and pushed many essential workers, care takers, parents, or owners of small enterprises to their limits. If everyone is affected, solidarity is strained within and across communities. In addition, while in many social resilience indicator frameworks aspects such as the level of education or wealth are seen to contribute to resilience, our study highlights the impact of urban space and its features as key determinants to pandemic resilience. The lack of attention for the nature of the interaction within an urban system has been identified as one of the main shortcomings to measuring urban resilience (Ilmola, 2016). Here, we have put forward the notion of spatio-temporal activity bubbles as an alternative framework that makes transparent the interaction dynamic and allows us to identify how interactions in urban space change over time. Empirical research in other contexts is needed to further test and validate our framework. Second, while a wildfire or flood presents a sudden and imminent threat, the Covid-19 pandemic brought about important trade-offs between the risk of infection and other risks to health and well- being such as the impact of isolation or restricted access to essential services. Further trade-offs include the short- versus long-term implications. This framework is also able to explore and unpack some of the trade-offs that are related to social resilience:

5.4.1. Well-being versus health

Bridging social interactions across district boundaries, or larger activity bubbles, are associated with higher social resilience and well-being. However, it is especially these cross-district interactions that can contribute to the spread of a pandemic, leading to a '*ping pong effect*' potentially (re)importing diseases to low-case areas (Priesemann et al., 2021). Therefore, there is a trade-off between social resilience and diverse interactions (large activity bubbles) and constraining activities in space to prevent the spread of a pandemic. We have also shown that the shrinking of activity bubbles in space and time can potentially increase disease spread or have negative impacts on well-being in districts with insufficient services and amenities. When viewed together, we see that increased bonding activities within districts may enhance social resilience, in terms of health and well-being, if amenities are justly distributed across districts. While linking networks were not directly studied, we maintain that means for observing and measuring these bridging and bonding behaviours are essential for helping organizations respond effectively during a pandemic. The activity bubble framework allows decision- makers to measure the shrinking activity bubbles in space and time. Thereby, it can support balancing the very prominent health needs with the need for interaction to support social resilience and response diversity.

5.4.2. Short-term coping capacity versus long-term adaptation

Our activity bubbles show that all communities have been able to adapt. While often, resilience is measured on the short term as the ability to rapidly recover or cope from a shock event, this framework allows us to trace *how* communities adjust, and what the longer term implications may be. Especially the shrinking temporal bubbles for 'social gathering' and 'sports' (see Fig. 5) may cause repercussions that are not immediately visible. While the effects of infection with the Covid-19 virus are felt in the near-term, we are just beginning to see the longer-term implications of the lockdowns on mental health, delayed education or elderly care. By analyzing these temporal changes, policy-makers can gain insights into (unintended) side-effects of their short- term policies, which may be harmful in the long run. More work is needed to understand the trade-offs and choices between different risks and risk perceptions, especially in the most vulnerable communities.

Next to the abrupt changes of human behaviour due to lockdowns and curfews, longitudinal research is needed of how pandemics and other major global events impact our physical environments in ways that shape human behaviour (Gehl, 2020). Here, the social resilience framework that we put forward can provide a starting point to analyze the emerging patterns of interaction that are facilitated by urban spaces and can help urban planners and policy-makers to observe changes in temporal and spatial bubbles that may impact overall health and well-being.

CRediT authorship contribution statement

Carissa Champlin: Conceptualization, Investigation, Resources, Writing – original draft, Writing – review & editing, Project administration, Visualization, Funding acquisition. **Mikhail Sirenko:** Software, Validation, Formal analysis, Resources, Data curation, Writing – review & editing, Visualization. **Tina Comes:** Conceptualization, Writing – review & editing.

Declaration of competing interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Data availability

The authors do not have permission to share data.

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Appendix A

Table 5
Socio-demographic statistics by district according to open source data.

Indicator	Centrum	Laakkwartier en Spoorwijk	Ypenburg
Socio-demographic:			
Age group (%)			
<30	33	39	35
30–50	33	31	29
>50	31	24	31
Education level (%)			
Primary and secondary	23	38	27
Mid-professional	31	40	37
Higher education	46	21	36
Income group (%)			
<30,000	57.4	59.1	26.1
30,000-58,500	29.3	34.1	37.1
>58,500	13.3	6.8	36.9

Source: Den Haag in Cijfers (yr. 2021).

References

Adger, W. N. (2000). Social and ecological resilience: Are they related? *Progress in Human Geography, 24*(3), 347–364.
Aldrich, D. P., & Meyer, M. A. (2015). Social capital and community resilience. *American Behavioral Scientist, 59*(2), 254–269.
Alraouf, A. A. (2021). The new normal or the forgotten normal: Contesting covid-19 impact on contemporary architecture and urbanism. *Archnet-IJAR: International Journal of Architectural Research, 15*(1), 167–188.
Balletto, G., Ladu, M., Milesi, A., & Borruso, G. (2021). A methodological approach on disused public properties in the 15-minute city perspective. *Sustainability, 13*(2), 593.
Bartscher, A. K., Seitz, S., Siegloch, S., Slotwinski, M., & Wehrhöfer, N. (2021). Social capital and the spread of covid-19: Insights from European countries. *Journal of Health Economics, 80*, Article 102531.
Biddle, L., Wahedi, K., & Bozorgmehr, K. (2020). Health system resilience: A literature review of empirical research. *Health Policy and Planning, 35*(8), 1084–1109.
Biloria, N., Reddy, P., Fatimah, Y. A., & Mehta, D. (2020). Urban wellbeing in the contemporary city. In *Data-driven multivalence in the built environment* (pp. 317–335). Springer.
Boersma, K., Berg, R., Rijbroek, J., Ardai, P., Azarhoosh, F., Forozesh, F., de Kort, S., van Scheepstal, A. J., & Bos, J. (2022). Exploring the potential of local stakeholders'involvement in crisis management. The living lab approach in a case study from Amsterdam. *International Journal of Disaster Risk Reduction, 79*, Article 103179.
Boonstra, B., Claessens, S., Warsen, R., & Van Meerkerk, I. (2022). Keep going on. A qualitative comparative analysis on the durability of solidarity initiatives during and after crisis. *Public Administration*, 1–18.
Chang, S., Pierson, E., Koh, P. W., Gerardin, J., Redbird, B., Grusky, D., & Leskovec, J. (2020). Mobility network models of covid-19 explain inequities and inform reopening. *Nature*, 1–6.
Comes, T. (2016). Designing for networked community resilience. *Procedia Engineering, 159*, 6–11.
Comes, T., Van de Walle, B., & Van Wassenhove, L. (2020). The coordination-information bubble in humanitarian response: Theoretical foundations and empirical investigations. *Production and Operations Management, 29*(11), 2484–2507.
Copeland, S., Comes, T., Bach, S., Nagenborg, M., Schulte, Y., & Doorn, N. (2020). Measuring social resilience: Trade-offs, challenges and opportunities for indicator models in transforming societies. *International Journal of Disaster Risk Reduction, 51*, Article 101799.
Cox, R. S., & Perry, K.-M. E. (2011). Like a fish out of water: Reconsidering disaster recovery and the role of place and social capital in community disaster resilience. *American Journal of Community Psychology, 48*(3), 395–411.
Cutter, S. L. (2016). Resilience to what? Resilience for whom? *The Geographical Journal, 182*(2), 110–113.
Davoudi, S., Brooks, E., & Mehmood, A. (2013). Evolutionary resilience and strategies for climate adaptation. *Planning Practice & Research, 28*(3), 307–322.
Dempsey, N., Brown, C., Raman, S., Porta, S., Jenks, M., Jones, C., & Bramley, G. (2010). Elements of urban form. In *Dimensions of the sustainable city* (pp. 21–51). Springer.
Doorn, N. (2017). Resilience indicators: Opportunities for including distributive justice concerns in disaster management. *Journal of Risk Research, 20*(6), 711–731.
Eaton, L. A., & Kalichman, S. C. (2020). Social and behavioral health responses to covid-19: Lessons learned from four decades of an HIV pandemic. *Journal of Behavioral Medicine, 43*(3), 341–345.
Ettema, D., & Schekkerman, M. (2016). How do spatial characteristics influence well-being and mental health? Comparing the effect of objective and subjective characteristics at different spatial scales. *Travel Behaviour and Society, 5*, 56–67.
Ferguson, N., Laydon, D., Nedjati Gilani, G., Imai, N., Ainslie, K., Baguelin, M., Bhatia, S., Boonyasiri, A., Cucunuba Perez, Z., Cuomo-Dannenburg, G., et al. (2020). *Report 9: Impact of non-pharmaceutical interventions (NPIs) to reduce COVID19 mortality and healthcare demand*.
Florida, R., Rodríguez-Pose, A., & Storper, M. (2021). Cities in a post-Covid world. *Urban Studies*, 1–2. https://doi.org/10.1177/00420980211018072
Fraser, T., & Aldrich, D. P. (2021). The dual effect of social ties on covid-19 spread in Japan. *Scientific Reports, 11*(1), 1–12.
Gehl, J. (2020). *Public space and public life during covid 19*. Copenhagen: Gehl Institute.
Geurs, K. T., & Van Wee, B. (2004). Accessibility evaluation of land-use and transport strategies: Review and research directions. *Journal of Transport Geography, 12*(2), 127–140.
Guterres, A. (2020). *Covid-19 in an urban world* accessed online https://www.un.org/en/coronavirus/covid-19-urban-world.
Guzman, L. A., Arellana, J., Oviedo, D., & Aristizábal, C. A. M. (2021). Covid-19, activity and mobility patterns in Bogotá. are we ready for a '15-minute city'? *Travel Behaviour and Society, 24*, 245–256.
Ilmola, L. (2016). Approaches to measurement of urban resilience. In *Urban resilience* (pp. 207–237). Springer.
Jabareen, Y., & Eizenberg, E. (2021). The failure of urban forms under the covid-19 epidemic: Towards a more just urbanism. *The Town Planning Review, 92*(1), 57–63.
Jamshed, A., Birkmann, J., Rana, I. A., & Feldmeyer, D. (2020). The effect of spatial proximity to cities on rural vulnerability against flooding: An indicator based approach. *Ecological Indicators, 118*, Article 106704.
Jones, L., A Constas, M., Matthews, N., & Verkaart, S. (2021). Advancing resilience measure- ment. *Nature Sustainability, 4*(4), 288–289.
Jordahl, K., den Bossche, J. V., Fleischmann, M., Wasserman, J., McBride, J., Gerard, J., Tratner, J., Perry, M., Badaracco, A. G., Farmer, C., Hjelle, G. A., Snow, A. D., Cochran, M., Gillies, S., Culbertson, L., Bartos, M., Eubank, N., Maxalbert, Bilogur, A., … Leblanc, F. (2020). *Geopandas/Geopandas: v0.8.1*.
Kadushin, C. (2004). Too much investment in social capital? *Social Networks, 1*(26), 75–90.
Kahila-Tani, M., Kyttä, M., & Geertman, S. (2019). Does mapping improve public participation? Exploring the pros and cons of using public participation GIS in urban planning practices. *Landscape and Urban Planning, 186*, 45–55.
Keck, M., & Sakdapolrak, P. (2013). What is social resilience? Lessons learned and ways forward. *Erdkunde*, 5–19.

Khavarian-Garmsir, A. R., Sharifi, A., & Moradpour, N. (2021). Are high-density districts more vulnerable to the covid-19 pandemic? *Sustainable Cities and Society, 70*, Article 102911.
Maguire, B., & Hagan, P. (2007). Disasters and communities: Understanding social resilience. *Australian Journal of Emergency Management, 22*(2), 16–20.
McGrail, D. J., Dai, J., McAndrews, K. M., & Kalluri, R. (2020). Enacting national social distancing policies corresponds with dramatic reduction in COVID19 infection rates. *PloS One, 15*(7), Article e0236619.
McPhearson, T., Andersson, E., Elmqvist, T., & Frantzeskaki, N. (2015). Resilience of and through urban ecosystem services. *Ecosystem Services, 12*, 152–156.
Meerow, S., Newell, J. P., & Stults, M. (2016). Defining urban resilience: A review. *Landscape and Urban Planning, 147*, 38–49.
Mitchell, T., & Harris, K. (2012). In *Resilience: A risk management approach. ODI background note* (pp. 1–7).
Mokhtarian, P. L., & Chen, C. (2004). Ttb or not Ttb, that is the question: A review and analysis of the empirical literature on travel time (and money) budgets. *Transportation Research Part A: Policy and Practice, 38*(9–10), 643–675.
Moreno, C., Allam, Z., Chabaud, D., Gall, C., & Pratlong, F. (2021). Introducing the "15-minute city": Sustainability, resilience and place identity in future post-pandemic cities. *Smart Cities, 4*(1), 93–111.
Mouratidis, K., & Yiannakou, A. (2022). Covid-19 and urban planning: Built environment, health, and well-being in Greek cities before and during the pandemic. *Cities, 121*, Article 103491.
Mouter, N., Hernandez, J. I., & Itten, A. V. (2021). Public participation in crisis policymaking. How 30,000 Dutch citizens advised their government on relaxing covid-19 lockdown measures. *PloS one, 16*(5), Article e0250614.
Nakagawa, Y., & Shaw, R. (2004). Social capital: A missing link to disaster recovery. *International Journal of Mass Emergencies and Disasters, 22*(1), 5–34.
Norris, F. H., Stevens, S. P., Pfefferbaum, B., Wyche, K. F., & Pfefferbaum, R. L. (2008). Community resilience as a metaphor, theory, set of capacities, and strategy for disaster readiness. *American Journal of Community Psychology, 41*(1), 127–150.
Östh, J., Dolciotti, M., Reggiani, A., & Nijkamp, P. (2018). Social capital, resilience and accessibility in urban systems: a study on Sweden. *Networks and Spatial Economics, 18*(2), 313–336.
Pariser, E. (2011). *The filter bubble: How the new personalized web is changing what we read and how we think*. Penguin.
Patacchini, E., Picard, P. M., & Zenou, Y. (2015). *Urban social structure, social capital and spatial proximity. Social Capital and Spatial Proximity (March 2015). CEPR Discussion Paper No. DP10501*.
Pfefferbaum, B., Van Horn, R. L., & Pfefferbaum, R. L. (2017). A conceptual framework to enhance community resilience using social capital. *Clinical Social Work Journal, 45*(2), 102–110.
Phillips, N. (2021). The coronavirus is here to stay-here's what that means. *Nature, 590*(7846), 382–384.
Pozoukidou, G., & Chatziyiannaki, Z. (2021). 15-minute city: Decomposing the new urban planning eutopia. *Sustainability, 13*(2), 928.
Priesemann, V., Brinkmann, M. M., Ciesek, S., Cuschieri, S., Czypionka, T., Giordano, G., Gur-dasani, D., Hanson, C., Hens, N., Iftekhar, E., et al. (2021). Calling for pan-European commitment for rapid and sustained reduction in sars-cov-2 infections. *The Lancet, 397*(10269), 92–93.
Reep, C., & Hupkens, C. (2021). Tijdlijn Coronamaatregelen (bron RIVM). Retrieved 20 November 2021 from https://www.cbs.nl/nl-nl/longread/statistische-trends/2021/ervaren-impact-corona-op-mentale-gezondheid-en-leefstijl/bijlage.
Rey, S. J., & Anselin, L. (2007). PySAL: A Python library of spatial analytical methods. *The Review of Regional Studies, 37*(1), 5–27.
Rijksoverheid. (2022). Hulp bij verbetering digitale Vaardijheden. Retrieved 13 December 2022 from https://www.rijksoverheid.nl/onderwerpen/laaggeletterdheid/hulp-bij-verbetering-digitale-vaardigheden.
Robinson, L., Schulz, J., Khilnani, A., Ono, H., Cotten, S. R., Mcclain, N., , … Casilli, A. A., et al. (2020). Digital inequalities in time of pandemic: Covid-19 exposure risk profiles and new forms of vulnerability. *First Monday, 25*(7). https://doi.org/10.5210/fm.v25i7.10845.
Roeters, A. (2017). Background of the time use survey. Retrieved 25 March 2022 from. In *Time use in the Nether- lands: Edition 1* https://digital.scp.nl/timeuse1/background-of-the-time-use-survey.
Rouberol, B. (2022). Haversine. https://pypi.org/project/haversine/.
Rutten, R., Westlund, H., & Boekema, F. (2010). The spatial dimension of social capital. *European Planning Studies, 18*(6), 863–871.
Saja, A. A., Goonetilleke, A., Teo, M., & Ziyath, A. M. (2019). A critical review of social resilience assessment frameworks in disaster management. *International Journal of Disaster Risk Reduction, 35*, Article 101096.
Saja, A. A., Teo, M., Goonetilleke, A., & Ziyath, A. M. (2021). Assessing social resilience in disaster management. *International Journal of Disaster Risk Reduction, 52*, Article 101957.
Schlosser, F., Maier, B. F., Jack, O., Hinrichs, D., Zachariae, A., & Brockmann, D. (2020). Covid-19 lockdown induces disease-mitigating structural changes in mobility networks. *Proceedings of the National Academy of Sciences, 117*(52), 32883–32890.
Shahid, M., Rana, I. A., Jamshed, A., Najam, F. A., Ali, A., & Aslam, A. (2022). Quantifying the role of social capital for enhancing urban resilience against climate crisis: Empirical evidence from formal and informal settlements of Pakistan. *Cities, 130*, Article 103851.
Sharifi, A. (2019). Resilient urban forms: A macro-scale analysis. *Cities, 85*, 1–14.
Sharifi, A., & Khavarian-Garmsir, A. R. (2020). The covid-19 pandemic: Impacts on cities and major lessons for urban planning, design, and management. *Science of the Total Environment*, 142391.
Sharma, M., Mindermann, S., Rogers-Smith, C., Leech, G., Snodin, B., Ahuja, J., Sandbrink, J. B., Monrad, J. T., Altman, G., Dhaliwal, G., et al. (2021). *Understanding the effectiveness of government interventions in Europe's second wave of covid-19*. MedRxiv.
Statistics Netherlands. (2022). CBS open data StatLine. Retrieved 25 March 2022 from https://opendata.cbs.nl/statline/portal.html?_la=nl&_catalog=CBS.
The Municipality of The Hague. (2022). The Hague in figures. Retrieved 25 March 2022 from https://denhaag.incijfers.nl/jive.
Toger, M., Kourtit, K., Nijkamp, P., & Östh, J. (2021). Mobility during the covid-19 pandemic: A data-driven time-geographic analysis of health-induced mobility changes. *Sustainability, 13*(7), 4027.
UN-Habitat. (2021). *Marib Urban Profile*. Retrieved 25 March 2022 from https://unhabitat.org/marib-urban-profile.
Voinov, A., Jenni, K., Gray, S., Kolagani, N., Glynn, P. D., Bommel, P., Prell, C., Zellner, M., Paolisso, M., Jordan, R., et al. (2018). Tools and methods in participatory modeling: Selecting the right tool for the job. *Environmental Modelling & Software, 109*, 232–255.
Westlund, H., Rutten, R., & Boekema, F. (2010). Social capital, distance, borders and levels of space: Conclusions and further issues. *European Planning Studies, 18*(6), 965–970.
World Health Organization. (2021). Who director-general's opening remarks at the media briefing on covid-19. https://www.who.int/director-general/speeches/detail/who-director-general-s-opening-remarks-at-the-media-briefing-on-covid-1914-december-2021 [Online; accessed 17-December-2021].
Yu, H., & Shaw, S.-L. (2008). Exploring potential human activities in physical and virtual spaces: A spatio-temporal GIS approach. *International Journal of Geographical Information Science, 22*(4), 409–430.