Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Elsevier hereby grants permission to make all its COVID-19-related research that is available on the COVID-19 resource centre - including this research content - immediately available in PubMed Central and other publicly funded repositories, such as the WHO COVID database with rights for unrestricted research re-use and analyses in any form or by any means with acknowledgement of the original source. These permissions are granted for free by Elsevier for as long as the COVID-19 resource centre remains active.
The microclimatic impacts of urban spaces on the behaviour of pandemics between propagation and containment: Case study historic Cairo

Doaa Salaheldin Ismail Elsayed *
Architectural Department, Faculty of Engineering, Kafrelsheikh University, Egypt

ARTICLE INFO

Keywords:
Urban space
Microclimatic performance
Quantitative assessment framework
Pandemic mitigation plans
Computer fluid dynamics
Solar radiation analysis

ABSTRACT

Although previous researches proved that frequent visits to urban spaces enhance the physical and mental health of people, most governments adopted lockdown policies after the outbreak of COVID-19. This decision has negatively impacted the wellbeing of communities and the livability of urban spaces. In this context the research questions how far the microclimatic conditions of urban space would influence its performance during respiratory pandemics? The study investigated this question through a dense literature survey including 47 scientific journal articles and governmental reports. The outputs were synthesized through a quantitative assessment framework. It detected the spatio-environmental parameters influencing the behaviour of respiratory pandemics in urban settings. To validate the framework’s outputs, the research applied case study sampling for 3 urban spaces in historic Cairo. It generated digital simulations and computations addressing solar radiation, natural ventilation, air temperature, and humidity, besides space dimension and number of users. The results illustrated the areas of adequate and poor microclimatic performance during pandemics. They are demonstrated through numerical tables, digital simulations, and graphs. Eventually, a concluding assessment framework selected the optimum urban space performance to be engaged in the public life of historic Cairo during lockdown periods.

1. Introduction

Infectious diseases remain a central challenge for public health in the twenty-first century with particular concern to human immunodeficiency viruses (Tulchinsky and Varavikova 2009). Severe acute respiratory syndrome coronavirus-2 (SARS-CoV-2) or COVID-19 (Tobaigy et al. 2020) has changed the way people live, work, communicate and integrate with their surrounding environment (Lee et al. 2020). It led to the death of more than 300,000 people, which urges the need for addressing problems of public health in urban planning debates (Rebecca Forman et al. 2020). The risk of global pandemics of viral mutations is related to the poor availability of cure and vaccine. Communities are asked then to live new normality based on social limitations and a series of precautionary procedures (Fong 2013). In this context, it’s essential to offer new approaches for managing the spatial, environmental, and social control, aiming to reduce the possibilities of droplet infection in urban settings (Tulchinsky and Varavikova 2009). Recently, the continuous re-emergence of epidemics is associated with global urbanization. Factors like the growth of urban densities, pollution, the

* Corresponding author.
E-mail address: doaa.elsayed@eng.kfs.edu.eg.

https://doi.org/10.1016/j.uclim.2021.100773
Received 20 August 2020; Received in revised form 6 January 2021; Accepted 6 January 2021
Available online 23 January 2021
2212-0955/© 2021 Elsevier B.V. All rights reserved.
decline of air quality, and the lack of open spaces, are influencing parameters affecting the propagation of viral infections. Accordingly, considering these factors would improve the quality of our urban planning strategies (Liu et al., 2019).

Unfortunately, urban planners are not effectively involved in discourses concerning pandemics’ urban mitigation. Even though, planners have historically achieved great impacts on developing urban fabrics associated with public health enhancement strategies. This was evident in Haussmann’s iconographic cityscape design for Paris, after the outbreak of the Cholera epidemic between 1832 and 1848. Later on, and during the 1910s-20s Howard’s Garden City ideals responded to the hygienic problems of cities after the propagation of the Spanish Flu. Currently, disaster management definition is mainly constrained to tangible calamities like earthquakes, floods, etc., with less consideration to intangible ones related to public health (Allam and Jones, 2020) (Megahed and Ghoneim 2020).

After the propagation of Corona virus, numerous countries applied complete or partial lockdown policies. Additional pandemic mitigation policies adopted non-pharmacological practices as well, like social distancing and self-isolation (Orea et al. 2020). The lockdown has negatively impacted the livability of urban spaces and the wellbeing of communities (Khan et al. 2020). These conditions highlighted the prerequisite for obtaining emergency preparedness planes based on new urban adaptation measures. Pandemic urban mitigation scenarios shall reflect the protocols published by the world health organisation (WHO) and respond to the sustainable development goals (SDGs) addressing public health and resilient human settlements.

During pandemic outbreaks, applying a disease prevention urban strategy is a necessity. It participates in reducing the urban pathogens accordingly; it improves public health and enhances the immunity system of communities. Furthermore, healthy urban spaces are strictly related to their environmental performance, which is based on both the prevailing climatic data and the features of the urban form (Muniz and Dominguez 2020). Thus, each space has its microclimatic behaviour (Li 2017). In this regard, the research aims to investigate the microclimatic performance of urban spaces during pandemic disease propagation, questioning how it could influence its containment. The research paper is investigating this topic through a network of urban spaces located in historic Cairo. It is one of the most livable, active, and hybrid urban agglomerations that was affected by the partial lockdown. Accordingly, the study performed a sequence of investigations on selected urban spaces including spatial studies, measurements, simulations, and assessments. The research aimed to evaluate the impacts of microclimatic conditions on the performance of each urban space during the pandemic era.

2. Review of literature

The literature review is based on highly impacted scientific journal papers investigating the nature of urban spaces, epidemiology, virology, environmental sciences, public health, and immunity-based urban systems. Public spaces symbolise our common assets and shared values, owned and sustained by our societies. The effect of the COVID-19 virus’s outbreak on public spaces is still uncertain. Questioning if it would lead to an individualistic approach for public space design? (Stevens and Tavares 2020). Although, previous researches proved that urban space design is an influencing tool for planning healthy cities besides, providing physical and mental health benefits (Liu et al., 2019). However, international health systems have applied non-pharmacological preventive practices like complete and partial lockdown in order to mitigate the impact of COVID-19 on communities. Unfortunately, practices based on social distancing affected the psychological wellbeing of people. It also caused mental illness expressed in post-traumatic stress symptoms, depression, and anxiety. Besides physical illness that is expressed in a remarkable declination of people’s immunity system (Mesa Vieira et al. 2020) (Stephan Barthel 2020). In this context, it’s more appropriate to adopt spatial distancing, which indicates maintaining the physical distance of at least 1 m from others while preserving social links. Spatial distance measures could remodel urban space in order to preserve the wellbeing of our cities while limiting the pandemic propagation (World health organisation 2020) (Mesa Vieira et al. 2020) (de Kadt and Gotz, 2020) (Franch-Pardo et al. 2020).

Nevertheless, spatial virus containment actions shall avoid disruptive factors like extreme densities, over-connected street networks, mono-functional neighbourhoods, insufficient natural ventilation, and lack of sun exposure. All of which increase the risk of epidemic outbreaks (Sun and Zhai 2020). However, urban spaces could promote physical and psychological secluded restorative environments (Samuelsson et al. 2020) (Lee et al. 2020) (Brizuela et al. 2019). In this regard, Samuelsson in 2020 mentioned that cities worldwide need to accept crises as a new reality and better explore the resilient nature of the urban systems. He added that pandemic urban mitigation strategies should be part of the sustainability agenda. Aiming to strive towards the third sustainable development goal (SDG) addressing good health and well-being, besides SDG 11 tackling sustainable and resilient cities (Samuelsson et al. 2020). While Lee highlighted the importance of building robust preparedness urban systems capable of coping with future pandemics (Lee et al. 2020) (Megahed and Ghoneim 2020). Acuto in 2020 questioned the perception of urban resilience and sustainability in the post-coronavirus world. He claimed that the current pandemic disease would drive a change in the way professionals think about cities and public health. He questioned the possibility to strive with contagious environments while controlling the infection. Acuto focused on the importance of urban experimentation to reform our public spaces and public behaviour towards web-based community building (Acuto 2020). In this context, the combination of epidemiology and urban space design has become an interdisciplinary discourse leading the theoretical and practical debates. Currently, urban spaces are capable of producing, containing, or propagating pathogens, which is an urgent topic to be utilized while setting up disease prevention strategies (Li 2017). Accordingly, new researches shall address the drivers of disease transmission in urban spaces. While detecting epidemic growth patterns across different pathogens, in order to simulate disease transmission models and implement infection control interventions (Viboud and Simonsen, 2016).

Recent researches discussing infectious disease control highlighted the climatic influences on both the containment and propagation of diseases. The outcomes performed predictive models for viral infections as a function of microclimatic parameters (Bariotakis et al. 2020). In this regard, the literature review is highlighting these parameters as follows.
Solar ultraviolet radiation is one of the most important environmental parameters affecting human health (Sleijffers et al. 2002). It is necessary to be exposed to sunrays but with precautions in order to avoid skin burns. The safe exposure level of solar radiation is limited to values of less than 4.5 KWh/m² per day. As it is considered harmful when the radiation amount exceeds 5.5 KWh/m² of daily exposure (Solargis, the world bank, 2017). In 2010 Asta Juzeniene mentioned that solar radiation is responsible for vitamin D photosynthesis. Thus, different seasonal intensities of solar radiations reflect a variation in Vitamin D status, which is based on ultraviolet B (UVB) radiation. She affirmed that exposure to UVB radiation plays an active role in decreasing the effect of diseases connected to respiratory pathogens. It suppresses the adaptive immunity while stimulating the innate non-specific immunity. Accordingly, it acts on reducing mortality possibilities (Asta Juzeniene et al. 2010). Further studies proved that the appropriate exposure to solar radiation attains an immunomodulatory effect. Thus it performs a natural protective manner against respiratory diseases (Swaminathan and Harrison, 2019) (Junaid and Rehman 2019) (Sleijffers et al. 2002). Several scientific articles confirmed that the deficiency of vitamin D is associated with several acute and chronic diseases. Researches revealed its correlation with infectious diseases, asthma, mood disorders besides autoimmune diseases. The Middle East and North Africa region (MENA) has a predominance of Hypovitaminosis D. Hence physicians recommend the daily sun exposure from 10 am to 3.00 pm only for 15 to 30 min, depending on the skin color. Researchers also added that the recommended daily amount for infants from 0 to 12 months is 400 international units (IU), while that for people from 1 to 70 years is 600 IU. But the recommended daily amount of exposure increases to reach 800 (IU) for the elderly above 70 years (Bassil et al. 2013)(Deborah Weatherspoon 2020). Likewise, preserving good air quality helps in vitamin D photosynthesis. In this regard, air pollution is one of the main factors leading to its deficiency in most urban settings by blocking the ultraviolet rays responsible for the photosynthesis process (Flies et al. 2019).

2.2. Air quality

Air pollution is rising to be a global problem due to its negative influence on public health, particularly with the current urbanization trends (Franco et al. 2019). Previous researches proved its correlation with respiratory diseases (Dan Norback et al. 2018). After the outbreak of the COVID-19 virus, several articles discussed how it accelerates virus diffusion under certain meteorological conditions like low wind speed (Franch-Pardo et al. 2020). Accordingly, it is growing to be an environmental risk factor (Flies et al. 2019). Therefore, air quality indices and modeling software are inevitable tools for assessing the city’s performance and capacity to improve its air quality during pandemics (Franco et al. 2019). Following the international air quality indices (AQI), adequate measures lie below 50 US AQI, and moderate ones range between 50 and 100 US AQI. But inadequate air quality values arise in areas scoring more than 100 US AQI. In this regard, providing suitable natural ventilation participates in improving air quality values. It reduces the percentage of pollutants in the air, in indoor as well as outdoor areas.

2.3. Natural ventilation (air velocity)

Efficient natural ventilation is an influencing factor in reducing cross-infection risks of respiratory diseases. Recent researches have observed the association between the accelerated diffusion of the COVID-19 virus and the predominant wind speed (Franch-Pardo et al. 2020)(Rendana 2020). Stevens and Tavares in 2020 pointed out that cities require well-ventilated urban spaces to cope with infectious respiratory diseases and achieving resilient urban environments (Stevens and Tavares 2020)(Leng et al. 2020). Moreover, Qian in 2010 added that sufficiently ventilated spaces are of lower infection risks. He claimed that ventilation reduces the concentration of air pathogens, through diluting airborne droplet nuclei. In 2008 Gao contributed with a further interpretation. He stated that high ventilation rates contribute to droplet dispersion, whereas low ventilated areas participate in the droplet accumulation over time. Consequently, it participates in increasing the infection probability (Gao et al. 2008).

After the spread of influenza, physicians recommended to keep the patients in open-air areas during the daytime as part of the treatment protocols. During this period open-air spaces corresponded to low concentration levels of infection (Nielsen 2009). But Morawska and Cao in 2020 alerted that precautions should be taken in terms of increased ventilation rates. They added that staying in the same airflow direction with an infected person would increase the cross-infection rates (Morawska and Cao 2020).

Nevertheless, Bouketta and Bouchahm (2020) studied the effect of wind speed as one of the most dominant factors responsible for classifying the urban microclimatic conditions. They explained that wind flow regains its free movement in open spaces. They also pointed out that the urban density of buildings, their orientation, and forms affect the rates of wind flow in open spaces. In addition to the H/W ratio (the ratio between the average height of the space and its width), and the urban profile, which influence the level of wind exposure. In this context Bouketta and Bouchahm, (2020) stated the fluctuation of accepted airstream in open spaces is between 1 and 5 m/s, which is considered the maximum velocity tolerated in the urban areas (Bouketta and Bouchahm, 2020; Leng et al. 2020).

2.4. Temperature and relative humidity (RH)%

Both temperature and relative humidity are additional factors controlling the microclimate of urban spaces and affect the outbreak of respiratory diseases. Franch-Pardo affirmed the association between the death rates in Wuhan (the epicenter of COVID-19 virus) and the ranges of temperature and relative humidity (Franch-Pardo et al. 2020). Following the research results of Lowen in 2008, He demonstrated that high cross-infection rates occur at a low temperature of 5 °C or > 5 °C and a low RH of 20–35%. But the droplet infection failed to arise at either a high RH (80% RH and 20 °C) or a high temperature (30 °C and 35% RH). He also pointed out that the
contact route transmission is insensitive to relative humidity or temperature (Lowen et al. 2008). Wang supported Lowen’s results in 2020 as he declared that high temperature and high humidity, respectively, reduce the transmission of COVID-19 (Wang et al. 2020).

During the SARS outbreak, Tan in 2005 stated that the increase of cases was associated with a range of temperatures between 16° and 28° C. Correspondingly, it created an environmental condition enabling the virus growth and reduces the immunity system (Tan et al. 2005).

2.5. Synthesis

The research aims at synthesising the dense output of the literature review through a quantitative assessment framework as shown in Table 1. It highlights the main parameters influencing pandemic mitigation in urban spaces. The framework is organised in five columns and eight rows. The former defines the quantitative parameters affecting pandemic mitigation. It investigates possible research tools and assessment scales. Finally, it displays the impact of these parameters on pandemic mitigation plans and illustrates the associated references. The latter concerns the detected parameters in the literature survey. On one hand, it identifies the spatial features of the urban space. It includes the height to width ratio (H:W), and the estimated number of users exploiting the spatial distance of 1.80–2 m. On the other hand, it highlights the environmental parameters influencing public health. It involves sun exposure and Vitamin D photosynthesis and its effect on the immunity system. Furthermore, it incorporates natural ventilation depending on the intensity of airspeed, illustrating its impact on droplet dilution. The assessment framework indicates the effects of air temperature and relative humidity% as well while detecting their role in the propagation of respiratory infectious diseases.

3. Research method

Based on the literature review, solar radiation and natural ventilation are two of the main climatic parameters influencing cross-infection possibilities. In this regard, digital measurements are applicable tools for computing these parameters (Bouketta and Bouchahm, 2020). These technologies supported the research in understanding the behaviour of urban forms according to their
Fig. 1. shows the historical spine of Al Muiz and the 3 studied urban spaces. Source: Author.
aerodynamic and solar performances. Following the research’s goals, the study selected three urban spaces in historic Cairo as sample case studies influenced by the identified parameters. It generated parametric measurements and digital simulations using Ladybug plug-in for Grasshopper-Rhino 6, and Autodesk computational fluid dynamics (CFD) software. Correspondingly, the research computed solar radiation (KWh/m²) and air velocity (m/s) values, respectively, in order to access the microclimatic performance of each urban space during pandemics.

3.1. Case study sampling

The research performed a case study sampling for three urban spaces in historic Cairo. The former is Bab Al Futouh square (A), the second is Bab Al Nasr square (b), while the latter is Beit Al-Qadi Square (C). Cairo lies at a latitude of 30.05°N and a longitude of 31.17°E. It is located in a hot-arid climatic zone. After investigating real-time satellite data and air quality indices, Cairo has shown a moderate air pollution level of 64 US AQI. The dominant pollutant is PM2.5 with a concentration of 18.1 μg/m³ (the tabulated measures are based on the results of the 2018 census). The sample urban spaces are located in Al-Jamaliyah district, which is one of the oldest areas in Cairo, with the following statistical data:

- Area = 2.08 km²
- Density = 18.063/km²
- Population = 37.517 person (males: 49% and females: 50.7%)
- Urban area = 100%

The three urban spaces are located along Al Muiz Street as shown in Fig. 1. It is the main north to south spine in historic Cairo. The street is connected to a distinguishable network of urban spaces, gates, and alleys. The selected urban spaces are the largest, most vibrant, and active open spaces along the street. They are capable of leading new designing methods seeking to achieve well-being and conviviality during pandemics. Although the urban spaces are located in the renovated portion of Al-Muiz Street, they were severely affected by the partial lock-down followed the propagation of the COVID-19 virus.

3.2. Measuring and modeling

The measuring and modeling phase enables configuring the urban forms of spaces, through which parametric computations and simulations will arise. Accordingly, the research designed digital models for the three selected urban spaces as shown in Fig. 2. The first model concerns Bab Al-Futouh square. It is a public open space adjacent to Al-Hakim Mosque. It has a triangular form with a total area of 1690 m² and a perimeter of 246 m. Its length is around 103 m, while its average width is around 20 m. The second model concerns the newly renovated Bab Al Nasr square. It is a squared form open space adjacent to a historical Ottoman Wekala (historical commercial building typology). Its total area equals 978 m², while its perimeter reaches 139 m. The third model concerns Beit Al-Qadi square. It is a rectangular open space with a total area of 1986 m² and a perimeter of 215 m. It is adjacent to Beit Al-Qadi historical building and gateway. The three open spaces and their urban settings are modeled using Rhino 6 software to operate parametric environmental computations.

3.3. Digital measurements and environmental simulation

After defining and modeling the urban spaces the research generated environmental simulations for estimating the solar radiation and airflow values.

3.3.1. Solar radiation analysis: (Ladybug-Grasshopper-Rhino 6 software)

Solar radiation analysis is a component offered by the ladybug-plugin. It enables calculating the radiation falling on an input
Fig. 3. shows a grasshopper canvas explaining the solar radiation analysis. Source: Author.
3.3.2. Airflow analysis: Autodesk CFD (Computational fluid dynamics) software

The study operated an airflow analysis using Autodesk CFD software. It is a tool performing computational fluid dynamic simulations. CFD is employed in the research to solve the design challenges related to aerodynamic performances. Its outcomes are represented in numerical and analytical solutions. Moreover, it generates mathematical models following the physical laws of materials. The behaviour of airflow differs according to the wind speed, direction, and space dimension, in addition to the influences of the surrounding context. Following the wind rose simulation, exploiting the Ladybug plug-in, Cairo experiences a prevailing northwest wind direction. The wind speed in summer reaches an average velocity equals to 5 m/s, while in winter it exceeds 7 m/s. The computational domains for the tested geometries of Bab Al Futouh and Bab Al Nasr squares are enclosed in a cube of 395 (W) x 522(L) x 284(H) m. The selected test geometries represent the ground surfaces of urban spaces (surface Brep), while the surrounding context signifies the sunlight blocking geometry (Context Brep). A grid size of 1 x 1 x 1 m is set to perform solar radiation analysis on the tested surface. The offset distance of the test point from the input geometry is set at 0.01 m as shown in Fig. 3.

Each urban space had a sufficient number of test points carrying out the computations as shown in Table 2. After running the simulation, the study generated the output values as shown in Fig. 4. The figure illustrated high solar radiation values in red color, while lower ones are represented in blue.

Table 2 shows the area, grid size, and distance from base and number of test points applied for the solar radiation analysis.

| Urban spaces       | Total Area (m$^2$) | Grid Size | Dist. from base | Test points |
|--------------------|--------------------|-----------|-----------------|-------------|
| A) Bab Al Futouh   | 1690               | 1 x 1     | 0.01            | 1798        |
| B) Bab Al Nasr     | 978                | 1 x 1     | 0.01            | 3242        |
| C) Beit Al Qadi    | 1986               | 1 x 1     | 0.01            | 3583        |

3.3.2. Airflow analysis: Autodesk CFD (Computational fluid dynamics) software

The study anticipated crossing over obstacles faced by planners and urbanists in what concerns the design of pandemic-resilient urban spaces. It mapped the areas according to their optimum microclimatic performance in terms of solar radiation and air movement as shown in Fig. 9. The assigned areas in black require minimum architectural, urban, or technological interventions to reach an acceptable microclimatic behaviour over the year. It recorded 1297 m$^2$ (37% of its total area) of adequate microclimatic conditions over the year. Nevertheless, Bab Al Nasr square reported the lowest microclimatic performance. It displayed an adequate area equals 226 m$^2$ (7.7% of its total area) over the year. The study compared the results of the three urban spaces. It reported that Bab Al Futouh square achieved the maximum area of acceptable microclimatic behaviour over the year. It recorded 1297 m$^2$, which is considered 76% of its total area. Although Beit Al Qadi square reported higher values than the former during summer, it had lower year-round calculations. The public square achieved an adequate area in summer equals 727 m$^2$ (37% of its total area). But it decreased to reach only 509 m$^2$ (26% of the total area) over the year. Nevertheless, Bab Al Nasr square reported the lowest microclimatic performance. It displayed an adequate area equals 226 m$^2$ (23% of its total area) in summer and 533 m$^2$ (54% of its total area) in winter. However, it recorded only an area equals 76 m$^2$ (7.7% of its total area) of adequate microclimatic conditions over the year.

The research outputs are synthesized in Tables 4, 5, and 6. The tables are illustrating the surface areas (m$^2$) of adequate solar radiation (KWh/m$^2$) and wind speed values (m/s) in both summer and winter periods. The research computed the areas following the quantitative assessment framework for the Spatio-environmental parameters concerning urban spaces during pandemics, illustrated in Table 1. The investigations are assigned to the three urban spaces of Bab Al Futouh (A), Bab Al Nasr (B), and Beit Al Qadi (C). On one hand, Table 4 illustrated three solar climatic zones of different impacts on public health. These zones are whether improving the immunity system by enabling Vitamin D photosynthesis or causing skin burns. On the other hand, Table 5 detected areas of adequate air velocity magnitudes, which would dilute infectious droplets and decrease cross-infection probabilities. Eventually, Table 6 fused the previous results. It detected the surface areas (m$^2$) securing healthy microclimatic conditions in summer, winter, and over the course of the year in times of pandemic propagation.

4. Results and discussion

The research outputs are synthesized in Tables 4, 5, and 6. The tables are illustrating the surface areas (m$^2$) of adequate solar radiation (KWh/m$^2$) and wind speed values (m/s) in both summer and winter periods. The research computed the areas following the quantitative assessment framework for the Spatio-environmental parameters concerning urban spaces during pandemics, illustrated in Table 1. The investigations are assigned to the three urban spaces of Bab Al Futouh (A), Bab Al Nasr (B), and Beit Al Qadi (C). On one hand, Table 4 illustrated three solar climatic zones of different impacts on public health. These zones are whether improving the immunity system by enabling Vitamin D photosynthesis or causing skin burns. On the other hand, Table 5 detected areas of adequate air velocity magnitudes, which would dilute infectious droplets and decrease cross-infection probabilities. Eventually, Table 6 fused the previous results. It detected the surface areas (m$^2$) securing healthy microclimatic conditions in summer, winter, and over the course of the year in times of pandemic propagation.

The study compared the results of the three urban spaces. It reported that Bab Al Futouh square achieved the maximum area of acceptable microclimatic behaviour over the year. It recorded 1297 m$^2$, which is considered 76% of its total area. Although Beit Al Qadi square reported higher values than the former during summer, it had lower year-round calculations. The public square achieved an adequate area in summer equals 727 m$^2$ (37% of its total area). But it decreased to reach only 509 m$^2$ (26% of the total area) over the year. Nevertheless, Bab Al Nasr square reported the lowest microclimatic performance. It displayed an adequate area equals 226 m$^2$ (23% of its total area) in summer and 533 m$^2$ (54% of its total area) in winter. However, it recorded only an area equals 76 m$^2$ (7.7% of its total area) of adequate microclimatic conditions over the year.

Subsequently, the research illustrated the numerical values with graphical models clarifying the solar radiation (KWh/m$^2$) and air velocity (cm/s) values as shown in Figs. 7 and 8. They are compared to the maximum and minimum ranges indicating the adequate standards for both parameters. These graphical illustrations are elucidating the impact of each space on public health.

The study anticipated crossing over obstacles faced by planners and urbanists in what concerns the design of pandemic-resilient urban spaces. It mapped the areas according to their optimum microclimatic performance in terms of solar radiation and air movement as shown in Fig. 9. The assigned areas in black require minimum architectural, urban, or technological interventions to reach an
Fig. 4. shows the values of the solar radiation analysis (KWh/m²) in summer and winter for the 3 urban spaces. Source: Author.
efficient environmental performance during pandemics. The final results are mapped following their behaviour in summer, winter, and year-round. This synthesis is considered the initial analysis aiming to comprehend the urban physics of open spaces while enabling efficient pandemic preparedness strategies to arise.

Ultimately, the study performed a spatio-environmental assessment for the selected urban spaces as shown in Table 7. It is a validation for the parametric synthesis illustrated in Table 1 in the literature review. The assessment matrix evaluated the space’s dimensions and ratios (H: W ratio), besides the maximum number of users following a spatial distance of 1.80 m. Moreover, it illustrated the optimum microclimatic performance in summer, winter, and year-round expressed in areas (m²). The assessment matrix assigned a constant value for the AQI equals 62 (air quality index in Cairo) and an average value for the air temperature equals 35 °C in summer and 19 °C in winter. Nevertheless, it adjusted the average relative humidity percentage to 58% in summer and 50–61% in winter.

The evaluation provided an equal weighting for all points besides assigning a scale from 1 to 3 for evaluating the different quantities. Following this scale (1) represented the lowest values, while (3) recorded the highest ones. The assessment criteria confirmed that Bab Al Futouh square (A) achieved the highest total score of 3/5 as shown in Fig. 10.

The study is promoting a new design typology configuring urban spaces according to the measures of public safety. It assessed three case study spaces to predict the ideal model offering the optimum urban and environmental performance during pandemics. On one hand, the study encourages the immediate activation of a network of open spaces to be utilized for public use. This network would play a key role in maintaining the physical and mental health of people during lock down periods (Bab Al Futouh square). On the other hand, it urges upgrading and retrofitting open spaces of poor microclimatic behaviour (Bab Al-Nasr square). These actions would permit occasional intrusions of artificial technologies incorporating outdoor ventilators and air cleaning devices. Furthermore, retrofitting processes shall empower landscaping, urban and architectural interventions that are capable of improving the futuristic microclimatic assessment of spaces.

The adopted research method is based on quantitative data computation, simulation, and modeling. It participates in the rise of big data analysis concerning urban areas. Nevertheless, it enables the realization of a fast, efficient, and scientific decision-making process based on a rich database in this time of uncertainty. Currently, pandemic mitigation urban planning is playing an influencing role during the coming years that are distinguished by high expectations for pandemic outbreaks. The study offers a new lens perceiving open space design through urban micro-climatic studies.

5. Conclusion

Assessing and managing the performance of open spaces during pandemics is considered one of the main futuristic challenges. In this context, environmental and geographic factors are playing an influencing role in mitigating infectious respiratory diseases. The research highlighted the urgency of this topic from an interdisciplinary perspective after the outbreak of COVID-19. Questioning how far urban settings would reduce virus propagation. The research underlined the importance of performing proactive planning for achieving pandemic mitigation strategies. It focused on understanding the influencing microclimatic parameters for open spaces. Besides analysing their role, whether in reducing the cross-infection possibilities or increasing people’s innate immunity. The research calibrated the infection probability of respiratory diseases in urban spaces based on a number of spatial and environmental parameters. According to the literature review, sufficient exposure to solar radiation and natural ventilation were the most influencing factors guiding pandemic containment. Nevertheless, the study underlined the impacts of other environmental factors including air quality,
Fig. 6. shows the air velocity magnitude in cm/s in summer and winter for the 3 urban spaces, underlining areas of air turbulences. Source: Author.

Table 3 shows the parameters assigned for the airflow simulations through CFD software. Source: Author.

| Urban spaces  | Wind speed m/s | Pressure (Pa) | Iteration no. | Plane height (m) | Domain size (m) |
|---------------|----------------|---------------|---------------|------------------|----------------|
|               | Summer         | Winter        |               |                  |                |
| A) Bab Al Futouh | 5              | 7             | 0             | 100              | 1.5            | 395x522x 85    |
| B) Bab Al Nasr  | 5              | 7             | 0             | 100              | 1.5            | 395x522x 85    |
| C) Beit Al-Qadi | 5              | 7             | 0             | 100              | 1.5            | 283x312x 40    |
after investigating three of the main liveable open spaces in historic Cairo, exploiting digital measurements and simulations the research designed a microclimatic assessment matrix. It is composed of a number of environmental and spatial parameters. The Assessment prioritised and categorised the spaces of adequate microclimatic behaviour to be engaged in public life during lockdown periods. Furthermore, it highlighted the open spaces of poor microclimatic performance. It also indorsed their involvement in a secluded restorative process adopting pathogenic limitation and infection control interventions. The research’s outcomes recommended Bab Al Futouh Square to be employed for public use during pandemics. It achieved a score of 3/5 compared to Bab Al Nasr and Beit Al-Qadi squares, which obtained 1/5 and 2/5, respectively.

According to the novelty of the topic, this assessment remains theoretical as long as it is validated with lab tests and onsite measurements. The research responds to the imperative demand requiring the involvement of planners and urbanists in pandemic disaster management strategies. It offers tools for understanding, measuring, and assessing the performance of urban spaces. These tools could be employed in futuristic preparedness protocols and partnerships with the health sector. Furthermore, The study aims to enrich the database concerning the behaviour of urban spaces during pandemics. It intends to facilitate the mission of governors and decision-makers in what concerns the design and management of pandemic mitigation preparedness plans.

Finally, this work highlights a mind shift in designing open spaces, combining epidemiology with urban space design strategies. It offers an insight linking urban planning, city intelligence, and wellbeing, besides inspiring more permanent changes, and creative patterns for pre and post-pandemic periods.

| Spaces                        | Summer (KWh/m²) | Scale (KWh/m²) | Area (m²) | Winter (KWh/m²) | Scale (KWh/m²) | Area (m²) |
|-------------------------------|-----------------|----------------|-----------|-----------------|----------------|-----------|
| Bab Al Futouh 1690 m² 246 m   | >522            | >5.5           | >943      | >219            | <4.5           | >623      |
| Bab Al Nasr 978 m² Perimeter139m | 406-464         | 4.5-5.5        | 649       | 195-219         | 895            | 172       |
| Beit Al-Qadi 1986 m² 215 perimeter | <348            | <4.5           | <98       | <170            | <128           | 597       |

| Spaces                        | Summer (cm/s) | Scale m/s | Area (m²) | Winter (cm/s) | Scale m/s | Area (m²) |
|-------------------------------|---------------|-----------|-----------|---------------|-----------|-----------|
| Bab Al Futouh 1690 m² 246 m   | >500          | >5        | 0         | >500          | >5        | 0         |
| Bab Al Nasr 978 m² Perimeter139m | 250-500       | 2.5-5     | 1139      | 250-350       | 2.5-5     | 1294      |
| Beit Al-Qadi 1986 m² 215 perimeter | >500          | >5        | 0         | >500          | >5        | 21        |

| Square | Total area (m²) | Healthy area in summer (m²) | % Healthy area in winter (m²) | % Healthy area all year (m²) | % |
|--------|----------------|----------------------------|-----------------------------|------------------------------|---|
| Bab Al Futouh | 1690        | 516                        | 31%                         | 1297                         | 77% | 1297 | 76% |
| Bab Al Nasr  | 978         | 226                        | 23%                         | 533                          | 54%  | 76   | 7.7% |
| Beit Al-Qadi | 1986        | 727                        | 37%                         | 1211                         | 61%  | 509  | 26% |
Fig. 7. shows the solar radiation values (KWh/m$^2$) in relation to the areas (m$^2$) in summer and winter days. Source: Author.
Fig. 8. shows the air velocity magnitude (cm/s) values in relation to the areas (m²) in summer and winter days. Source: Author.
Fig. 9. shows a graphical representation for the spaces achieving healthy microclimatic condition in each urban space. Source: Author.

Table 7 shows the spatio-environmental assessment for the 3 urban spaces. Source: Author.

| Parameters                                                | Bab Al Futouh (A) | Bab Al Nasr (B) | Beit Al Qadi (C) | Optimum         |
|-----------------------------------------------------------|-------------------|-----------------|------------------|-----------------|
| 1- Healthy space dimensions (H:W ratio)                  | 0.16 (1)          | 0.80 (2)        | 0.4 (2)          | B, C            |
| 3- Maximum number of users (1.80 m apart)                | 470 (3)           | 255 (2)         | 180 (1)          | A               |
| 4- Area percentage of efficient solar exposure and natural ventilation in summer. | 31% (2)           | 23% (1)         | 37% (3)          | C               |
| 5- Area percentage of efficient solar exposure and natural ventilation in winter. | 77% (3)           | 54% (1)         | 61% (2)          | A               |
| 6- Area percentage of efficient solar exposure and natural ventilation during the year | 76% (3)           | 7,7% (1)        | 26% (2)          | A               |
| 6- Air quality index (AQI)                               | 62                | 62              | 62               | –               |
| 7- Average air temperature (°C)                          | –35 °C (Summer)   | –35 °C (Summer) | –35 °C (Summer) | –               |
|                                                           | –19 °C (Winter)   | –19 °C (Winter) | –19 °C (Winter) | –               |
| 8- Relative humidity%                                     | - 58%(Summer)     | - 58%(Summer)   | - 58%(Summer)   | –               |
|                                                           | - 50-61%(Winter)  | - 50-61%(Winter)| - 50-61%(Winter)| –               |
| Total Score                                               | 3/5 (A)           |                 |                  |                 |
Funding
This research received no external funding.

Author statement
All persons who meet authorship criteria are listed as authors, and all authors certify that they have participated sufficiently in the work to take public responsibility for the content, including participation in the concept, design, analysis, writing, or revision of the manuscript.

Declaration of Competing Interest
The author declares no conflict of interest in the research paper.

References
Acuto, M., 2020. COVID-19: lessons for an urban(izing) world. One Earth. https://doi.org/10.1016/j.oneear.2020.04.004.
Allam, Zaheer, Jones, David S., 2020. Pandemic stricken cities on lockdown. Where are our planning and design professionals [now, then and into the future]? Land Use Policy 97, 104805. https://doi.org/10.1016/j.landusepol.2020.104805.
Bariotakis, M., Sourvinos, G., Castamas, E., Pirintsos, S., 2020. Climatic Influences on the Worldwide Spread of SARS-CoV-2. https://doi.org/10.1101/2020.03.19.20038158.
Barthel, Stephan, 2020. Coronavirus Highlights the Need for Open Green Spaces in Cities - Stockholm Resilience Centre [WWW Document]. https://www.stockholmarelionsence.org/research/research-news/2020-04-21-coronavirus-highlights-the-need-for-open-green-spaces-in-cities.html.
Bassil, D., Rahme, M., Hoteit, M., Fuleihan, G.E.-H., 2013. Hypovitaminosis D in the Middle East and North Africa. Dermatoendocrinol 5, 274–298. https://doi.org/10.4161/derm.25111.
Bouketta, S., Bouchahm, Y., 2020. Numerical evaluation of urban geometry’s control of wind movements in outdoor spaces during winter period. Case of Mediterranean climate. Renew. Energy 146, 1062–1069. https://doi.org/10.1016/j.renene.2019.07.012.
Brizuela, N.G., García-Chan, N., Pulido, H.G., Chowell, G., 2019. Understanding the role of urban design in disease spreading (preprint). Syst. Biol. https://doi.org/10.1101/766667.
Bouketta, S., Bouchahm, Y., 2020. Numerical evaluation of urban geometry’s control of wind movements in outdoor spaces during winter period. Case of Mediterranean climate. Renew. Energy 146, 1062–1069. https://doi.org/10.1016/j.renene.2019.07.012.
Junaid, K., Rehman, A., 2019. Impact of vitamin D on infectious disease-tuberculosis-a review. Clin. Nutri. Exper. 25, 1–10. https://doi.org/10.1016/j.cnlne.2019.02.003.
Juzeniene, Asta, Ma, Li Wei, Kwitniewski, Mateusz, 2010. The seasonality of pandemic and non-pandemic influenzas: the roles of solar radiation and vitamin D. Int. J. Infect. Dis. 14, e1099–e1105. https://doi.org/10.1016/j.ijid.2010.09.002.
de Kadt, Julia, Gotz, Graeme, 2020. Mapping Vulnerability to COVID-19 in Gauteng[GCRO [WWW Document]. https://www.gcro.ac.za/outputs/map-of-the-month/detail/mapping-vulnerability-to-covid-19/.
Khalig, Abdul, 2007. (PDF) Thermal Comfort Modelling of an Open Space (Sport Stadium). RMIT University, United Kingdom.
Khan, J., Hildingsson, R., Gartel, L., 2020. Sustainable welfare in Swedish cities: challenges of eco-social integration in urban sustainability governance. Sustainability 12, 383. https://doi.org/10.3390/su12010383.

Fig. 10. shows a graphical representation for the selected urban assessment criteria. Source: Author.
