Unidirectional pedestrian circulation: physical distancing in informal settlements

JUAN FERNÁNDEZ GONZÁLEZ
ANKIT GONGAL

“Author affiliations can be found in the back matter of this article

ABSTRACT
The COVID-19 pandemic has resulted in a wide range of spatial interventions to slow the spread of the virus. The spatial limitations of narrow public circulation spaces within informal settlements, which house over 1 billion people around the world, make it impossible for pedestrians to practice physical distancing (or social distancing). A flexible mathematical method, the Cluster Lane Method, is proposed for turning a planar circulation network of any size or complexity into a network of unidirectional lanes. This makes physical distancing possible in narrow circulation spaces by limiting face-to-face interactions. The opportunities and challenges are discussed for the implementation of this cost-efficient, low-tech solution. New notions and theorems are introduced for oriented graphs in graph theory.

PRACTICE RELEVANCE
A new approach based on graph theory is used to address the problem of COVID-19 contagion in the narrow public circulation networks of informal settlements. The Cluster Lane Method shows how to convert a planar circulation network of any size or complexity into a network of unidirectional lanes. This makes physical distancing possible in narrow circulation spaces by limiting face-to-face interactions between pedestrians. By involving the inhabitants of the informal settlement throughout the process, more adequate orientations of the lanes can be found.

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SPECIAL COLLECTION: URBAN SYSTEMS FOR SUSTAINABILITY AND HEALTH

Corresponding Author:
Juan Fernández González
520 Grosvenor Ave., Westmount, QC, Canada H3Y2S4
juan.fernandezgonzalez@mail.mcgill.ca

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1. INTRODUCTION

The transformative role of pandemics and disease in changing the trajectory of architectural thought and practice has been well documented. For example, Harriet Jordan argued how the 19th-century movement pushing for public parks was a response to the overcrowding and pollution brought about by industrialisation (Jordan 1994). Similarly, the cholera epidemic led administrators to lay the foundations for the now-ubiquitous sanitary and underground infrastructure. Baron Haussmann operated on what he considered the ‘sick’ city of Paris, creating wide boulevards, aqueducts and a major network of sewers and thus improving the city’s hygiene (Ingersoll 2013). These responses to disease have had a positive long-term impact on the health and sustainability of cities. However, the implementation of such solutions often requires the demolition and construction of large-scale infrastructures, which can take years or decades to implement.

It is highly likely that the current COVID-19 pandemic will trigger significant paradigm shifts in how urban infrastructure is designed in the long run. Yet, more immediate spatial interventions that are easily deployed and implemented are needed. In fact, urban environments have started to become more friendly to cyclists and pedestrians with the recent implementation of physical distancing guidelines in some of the world’s major cities (Bliss 2020), including Berlin, Montreal, Paris and Mexico City. However, physical distancing guidelines in public circulation spaces are only possible in places where there is enough room to expand the spatial layout.

Urban slums and informal settlements lack proper medical infrastructure, well-enforced sanitary standards or room for physical distancing and thus pose a significant threat to a successful response. According to ECOSOC (2020: 13), over 1 billion people lived in slums or informal settlements in 2018:

- The pandemic will hit the hardest the more than 1 billion slum dwellers worldwide. […]
- Urgent response plans are needed to prepare for and respond to outbreaks in informal settlements and slums.

The gravity of this situation is unquestionable.

This paper addresses the risk of COVID-19 contagion via airborne transmission in the narrow public circulation lanes of informal settlements. A low-tech, mathematical solution is proposed that limits face-to-face interactions among pedestrians. Thus, this strategy becomes an additional tool to combat the spread of disease.

The paper is structured as follows. Section 2.1 discusses the morphologies of informal settlements and their narrow public circulation lanes. Section 2.2 addresses the airborne transmission of COVID-19 and the role of physical distancing to reduce this transmission. Section 3 explores the urban origins of graph theory and the important role of this branch of mathematics on architecture and urban planning. Subsequently, section 4 introduces the Cluster Lane Method, which makes it possible to turn a planar circulation network into a network of unidirectional lanes, thus limiting face-to-face interactions between pedestrians while limiting circulation between different clusters of dwellings. Finally, Section 5 discusses the applications of the method to real informal settlements, along with the potential difficulties and improvements of these applications. Section 6 concludes. Appendix 1 in the supplemental data online defines basic notions of graph theory; and Appendix 2, also online, describes the Cluster Lane Method in a mathematically rigorous way by introducing new definitions and theorems in graph theory.

2. INFORMAL SETTLEMENTS AND COVID-19 CONTAGION

This section explores the spatial qualities of informal settlements and their narrow public circulation lanes. Some existing evidence on the airborne transmission of COVID-19 is presented, together with the practice of physical distancing to reduce this transmission.
2.1 DENSE URBAN SETTLEMENTS AND THEIR PUBLIC CIRCULATION NETWORKS

Dharavi in Mumbai, India, is one of the world’s densest slums and fits close to 1 million people into an area roughly two-thirds the size of Central Park in New York (Figure 1). It contains a labyrinthine circulation network with some lanes barely wide enough to outstretch out both one’s arms, let alone follow the recommended physical distancing standards. Underneath the apparent chaos in Dharavi lies a thriving informal economy with an estimated worth of US£1 billion (McDougall 2007). Unfortunately, most of the strategies deployed in Western countries’ major cities are hardly applicable in such dense slums. Physical distancing is practically impossible, while automated and touchless technologies are far from being available in a locality that lacks basic sanitary infrastructure. By combining a strict India-wide lockdown and a rigorous proactive testing protocol, Dharavi seemed to be keeping the COVID-19 outbreak relatively under control by mid-June 2020 (Biswas 2020). However, by mid-July, 40–60% of the population living in the slums of Mumbai were infected with COVID-19, where:

67% of households rely on community toilets, soap and clean water are scarce and physical distancing is impossible.

(Bai et al. 2020)

Trailing the US with 33,165,820 confirmed COVID-19 cases, the second and third countries with the most confirmed cases on 25 May 2021 were India (26,948,874) and Brazil (16,194,209), according to the Johns Hopkins Coronavirus Resource Center (2021). An Indian 2011 census identified 64 million people living in city slums nationwide (Johnson 2013). In 2014, it was reported that 22.3% of Brazil’s urban population lived in slums (or favelas), according to the World Bank collection of development indicators (Trading Economics 2020). As much less dense settlements have struggled with fresh COVID-19 outbreaks when reopening after lockdown, it is of primary importance to develop low-tech solutions to slow the transmission of disease in the circulation spaces of the congested urban developments of informal settlements.

Informal settlements around the world vary in morphology, but exhibit similar patterns which include narrow public circulation lanes. Dovey & King (2011) propose a typology of different informal settlement types. These morphological types are characterised, in part, by their relationships with the formal structures of the surrounding urban fabric, with other informal structures and/or with the topography. Some types are attached or inserted between existing buildings, where ‘at times the entry through the streetwall is nothing more than a half metre gap’. Others are ‘inserted into the smallest fragments of leftover space’ (Dovey & King 2011: 17). Because of the congested nature of informal settlements and their public circulation spaces, pedestrians walk in close proximity to each other. Some lanes might be used as congregate spaces or as extensions of a dwelling or business. Moreover, even though these circulation spaces are mostly outdoors, some can be fairly enclosed and even covered by roof overhangs. This is illustrated in Figure 1, since numerous circulation lanes appear to be covered in the aerial view. Airflow and ventilation are thus more limited there than in the wide streets of formal urban neighbourhoods. Whether or not these circulation spaces may behave as a hybrid between outdoor and indoor spaces, the proximity of pedestrians can lead to COVID-19 contagion because of airborne transmission, as discussed below.
2.2 AIRBORNE TRANSMISSION OF COVID-19 AND PHYSICAL DISTANCING

COVID-19 spreads through airborne transmission. A Lancet report entitled ‘Ten scientific reasons in support of airborne transmission of SARS-CoV-2’ supports this claim. It states that there is ‘consistent, strong evidence that SARS-CoV-2 spreads by airborne transmission’, and although other types of transmission might contribute, Greenhalgh et al. (2021: 1604) believe that, ‘the airborne route is likely to be dominant’. Similarly, Morawska & Milton (2020: 2311) write that:

scientists have demonstrated beyond any reasonable doubt that viruses are released during exhalation, talking, and coughing in microdroplets small enough to remain aloft in air and pose a risk of exposure at distances beyond 1–2 m from an infected individual.

Additionally, the WHO (2021) states that a person:

can be infected when aerosols or droplets containing the virus are inhaled or come directly into contact with the eyes, nose or mouth.

To reduce the risk of airborne transmission, ‘physical distancing’ can be practiced. This is defined as:

the practice of staying at least 6 feet away from others to avoid catching airborne diseases such as COVID-19.

(Maragakis 2020)

(The broader term ‘social distancing’, sometimes used interchangeably with ‘physical distancing’, means ‘staying home and away from others as much as possible to help prevent spread of COVID-19’ (Maragakis 2020) and will not be used throughout this article.) According to the Centers for Disease Control and Prevention (CDC) (2020):

Limiting close face-to-face contact with others is the best way to reduce the spread of [COVID-19].

Moreover, masks and other face coverings have proved to be essential to slow the spread of COVID-19. The CDC provides guidance for wearing masks in order to protect the person wearing the mask as well as others. It specifies that masks should be worn:

in addition to staying at least 6 feet apart, especially when indoors around people who don’t live in your household.

(CDC 2021)

Since masks are not substitutes for physical distancing, the latter should be practiced by pedestrians in all circumstances. In the case when not enough masks are available for a given population, physical distancing becomes even more crucial to slow the spread of COVID-19.

As discussed in section 1, the public circulation spaces within informal settlements are most often outdoors but may be covered and are most often very narrow. Physical distancing should not be disregarded in these scenarios since it can be practiced both indoors and outdoors. Even though the:

odds of indoor transmission was very high compared to outdoors (18.7 times; 95% confidence interval, 6.0–57.9)

a systematic review of outdoor transmission of SARS-CoV-2 concluded that ‘there are significant gaps in our understanding of specific pathways [of transmission]’ (Bulfone et al. 2020: 550). Physical distancing can generally be practiced more easily in outdoor spaces because they allow for:

airflow, ventilation, and lack of recycled air, which all minimize the theoretical risk of aerosol transmission through smaller respiratory droplets.

(Bulfone et al. 2020: 550)

However, circulation spaces in informal settlements do not possess ideal spatial qualities for airflow and ventilation, and thus outdoor transmission of COVID-19 should not be neglected.
To minimise the risk of outdoor transmission via face-to-face interactions in the narrow circulation lanes of informal settlements, and limit contagion between clusters of dwellings, the Cluster Lane Method uses graph theory. This branch of mathematics began with a problem dealing with the spatial arrangements of a city, as discussed in the following section.

3. URBAN ORIGINS OF GRAPH THEORY

Throughout history, several popular puzzles and problems relating to movement within an urban fabric have led to significant mathematical breakthroughs. One of these seemingly innocent problems, consisting of walks over a series of bridges, is called ‘The Seven Bridges of Königsberg’ (Figure 2). The prolific mathematician Leonhard Euler presented its solution, along with other findings, to the members of the St Petersburg Academy on 26 August 1735 (Benjamin et al. 2015).

Euler laid the foundations of a new branch of mathematics involving the ‘geometry of position’, which is now known as graph theory. This new approach involves simplifying spatial relationships between objects into diagrams of points (vertices) and lines (edges). Insights from the mathematical analysis of these graphs would lead to principles that would be valid for all similar graphs, of any size or complexity.

Since Euler’s solution, graph theory has become an important branch of both pure and applied mathematics. Numerous problems in geometry, topology, among others, have been solved with it since diverse mathematical structures can be embedded into graphs. Famous theorems have connections to graph theory: The Descartes–Euler Polyhedral Formula, along with the Euler characteristic applied to higher dimensions in algebraic topology and polyhedral combinatorics, relates the number of vertices \( V \), edges \( E \) and faces \( F \) in convex polyhedra as \( V + F - E = 2 \) (Weisstein 2020b); The Four Colour Theorem, renowned for being the first major theorem to be proved with a computer and for the controversy that came with it, states that ‘any map in a plane can be coloured using four colors in such a way that regions sharing a common boundary (other than a single point) do not share the same colour’ (Weisstein 2020a).

In architecture and urban planning, graph theory has played an important role which evolved in parallel with the implementation of computation in architectural practice and theory since the 1960s. Theodora Vardouli states that:

architects turned to structural abstraction in efforts to purify their inheritance of interwar Modern architecture from stylistic doctrines and empirical conventions. The graph’s amenability both to visual depiction and to mathematical analysis furnished it with a strategic position among modern mathematical varieties: graphs made structural abstraction visible and workable. By virtue of this property, graphs proliferated in architectural theory as harbingers of a veritably modern discipline founded on rationality and geared toward ensuring functional efficiency.

(Vardouli 2017: 3)
Graph theory provides tools to represent the underlying structures of circulation networks, building plans, spatial structures in cities and much more. Lionel March discussed the educational movement of ‘new mathematics’ during the 1950s, which aimed to change the teaching curriculum to include subjects such as graph theory, certain notions of combinatorics and set theory. These tools allowed March & Steadman (1974) to study the circulation systems of Frank Lloyd Wright’s architectural designs, among others. Thomas Grasl and Athanassios Economou explored possible design implementations of graph theory by generating floor plans of Palladian villas with an application embedded in a parametric computer-aided design (CAD) environment (Grasl & Economou 2018).

The mathematical aspect of this paper, thoroughly explained in Appendices 1 and 2 in the supplemental data online, focuses on oriented graphs. These are graphs for which orientations (or directions) are assigned to edges. They can represent circulation networks with both bi- and unidirectional lanes. The present method was inspired by the cost-efficient, low-tech solutions of unidirectional circulation in supermarkets and small retail environments during the early months of the COVID-19 pandemic. By using oriented graphs, the method generalises unidirectional pedestrian circulation to the scale of settlements, or any planar circulation network.

4. THE CLUSTER LANE METHOD

The Cluster Lane Method is a flexible mathematical method which makes it possible to turn any planar circulation network into a circulation network made of unidirectional lanes in such a way that any given location can be reached from any other location. A map of the settlement, generated with satellite images, geodata or participatory community mapping, is needed to apply the method. It is illustrated and described thoroughly, in mathematical terms, in Appendix 2 in the supplemental data online. The text and images in this section provide an overview of the method and highlight its most important notions.

In A Pattern Language, Christopher Alexander discusses the ‘House Cluster’, identified as Pattern 37:

people want to be part of a neighborly spatial cluster; contact between people sharing such a cluster is a vital function.

(Alexander et al. 1977: 198)

The Cluster Lane Method aims to adapt to the ways in which people live and is inspired by Alexander’s discussion. Although the dense housing typologies of informal settlements do not exactly match Alexander’s ‘house cluster’, the idea that clusters are the ‘natural focus of neighborly interaction’ guides the proposed method, since this also applies to informal settlements. For the sake of this method, a cluster of dwellings is a group of adjacent buildings. It is delimited by a boundary (the circulation lanes on its perimeter) and may contain additional circulation lanes within it.

The Cluster Lane Method can be simplified as follows: An entire informal settlement, which corresponds to a large cluster of dwellings, is subdivided into as many smaller clusters of dwellings as desired. Given these smaller clusters of dwellings, each lane of the circulation network is assigned an orientation. The subdivision of the clusters of dwellings is thoroughly explained in the Appendix 2 in the supplemental data online, as well as how the lanes are assigned unidirectional orientations. Figure 3 shows a particular example of an informal settlement and the resulting unidirectional circulation network after applying the Cluster Lane Method. Figure 3(c) illustrates selected clusters of dwellings in grey.

The unidirectional circulation networks proposed by the Cluster Lane Method are responsive to the urban fabric of informal settlements and their clusters of dwellings. An organisational hierarchy of three types of circulation lanes makes it possible for pedestrians to navigate the network. These types are:

- circulation around the boundary of a cluster of dwellings
- circulation within the boundary of a cluster of dwellings
- circulation between the boundaries of different clusters of dwellings.
This organisational hierarchy of lanes is present throughout the selected informal settlement’s entire circulation network. Two important properties are characteristic of the oriented circulation networks resulting from the Cluster Lane Method. First, people within a cluster of dwellings can move within the cluster without having to leave it (by using the lanes of types 1 and 2 only) (Figure 4a). This facilitates short walks and limits long detours. Second, people who have to cross one or more clusters of dwellings can go around them without having to enter them (by using the lanes of type 1 and type 3 only) (Figure 4b). This limits unnecessary traffic within clusters of dwellings. Thus, the Cluster Lane Method could reduce the chances of COVID-19 spreading between clusters of dwellings, slowing contagion within an informal settlement.

5. APPLICATIONS OF THE METHOD

This section presents the opportunities and challenges associated with the implementation of the Cluster Lane Method.

5.1 OPPORTUNITIES

Informal settlements and slums lack the top-down organisation inherent in planned urban developments like the Manhattan grid or the Barcelona superblocks. Their organic growth is often dictated by self-building principles responding to local constraints and can result in unique spatial organisations. Two of these principles are autonomous growth and continuous development, discussed by McGill University’s Minimum Cost Housing Group (Bhatt et al. 1990).

The spatial patterns of public circulation networks in informal settlements could be hard to discern when looking at a satellite image or plan because of their ‘organic’ or ‘free-form’ that is different from a rectilinear grid network. Orangi Town in Karachi (Pakistan), Neza in the State of Mexico (Mexico), Dhavari in Mumbai (India), Kibera in Nairobi (Kenya), Khayelitsha in Cape Town (South Africa) and Rocinha in Rio de Janeiro (Brazil) all present unique spatial qualities. Yet, regardless of the size and complexity of the circulation network, the Cluster Lane Method can always be applied, as demonstrated in Appendix 2 in the supplemental data online.
The present method corresponds to one of many applications of graph theory to address problems within informal settlements. For example, Brelsford et al. (2018) diagnose the lack of spatial accesses and related services within slums, which they call ‘the central physical problem of slums’ (Brelsford et al. 2018: 1). By using topology and graph theory on real maps of these settlements, infrastructure problems can be identified and then solved with algorithms. In a similar way to the method presented herein, they generalise their mathematical methods to any city block or neighbourhood. Additionally, by involving the settlement’s inhabitants throughout the decision-making process, they aim to provide ‘people-centric’ solutions aligned with their needs and resources. Readers are invited to learn more about their case studies in Cape Town and Mumbai discussed by Brelsford et al.

The method can provide a people-centric solution to limit COVID-19 contagion in these settlements by involving their inhabitants. Further research and testing would be necessary to find a site- and culture-specific implementation of the method. An anthropological study of how people inhabit a particular informal settlement would inform key strategies for implementation, for example, whether a bottom-up or a top-down approach would be well received depending on social norms surrounding authority and discipline. Regardless of local variants, it would be important to minimise distances between homes and significant spatial nodes such as landmarks, sanitary facilities, marketplaces or public institutions. By taking these factors into account, the clusters of dwellings could be strategically defined, with the help of Appendix 2 in the supplemental data online, in order to limit traffic between different clusters. In the case of a COVID-19 outbreak in one of the clusters, the method could facilitate the isolation of this cluster to protect the inhabitants of other clusters.

5.2 CHALLENGES

The implementation of the Cluster Lane Method could present some difficult challenges. The restructuring would disrupt existing circulation patterns, which could lead to non-compliance, confusion or inconvenience on part of the inhabitants. To prevent resentment among the inhabitants, it would be important to involve the community in as many steps of the process as possible. This would help to ensure that existing circulation patterns are accommodated in the final unidirectional network while also allowing all parties to arrive at a common set of objectives and priorities. When maps are not available, mapping entire informal settlements would be necessary to apply the method. The use of drones or satellite images, as well as mapping circulation networks on foot, could help produce these maps. The participation of residents in the mapping would help integrate existing circulation patterns and could potentially win the community’s support.

Romero et al. (2020) use a simple case model to compare the impact of one- versus two-way traffic within an academic building. While acknowledging that unidirectionality’s benefit in reducing the exposure per unit time can be made redundant by the increase in time spent moving through the space, they emphasise that one-way traffic is more useful for narrow corridors than wider ones and that the time spent in movement should be minimised more urgently. These conclusions are particularly relevant for cramped circulation spaces within informal settlements where crowd density, narrow passageways and long queues due to congestion are familiar shortcomings. Thus, the use of staggered time schedules and a cap on the number of people moving at any given time are essential for the successful implementation of unidirectional circulation networks.

Moreover, the Government of Canada recommends unidirectional circulation as part of its guidelines for the safe return to workplaces:

> Due to the width of circulation areas in most office environments, unidirectional circulation patterns for corridors throughout offices and workstations should be considered where possible

as well as for lockers, coat closets and other storage areas (Public Services and Procurement Canada 2020).

As previously noted, the unidirectional restructuring would lead to a recalibration of pedestrian density, with certain critical pathways being used more. However, this only highlights the crucial role that capping pedestrian occupancy limits and time allotments would play as the spacing between the people walking along the unidirectional lanes cannot be reduced below the minimum
health guidelines. The resultant holdup and extended waiting times could potentially frustrate pedestrians and lead them to disregard established rules of orientation. Boo (2012) examined the dangers and politics present in a Mumbai informal settlement and showcases the influence that people higher up in the social hierarchy play in enforcing local norms. Therefore, in order to make people comply with such transformative alterations to the circulation network or minimise rebellion, it would be decisive in getting the influential informal administrators of the settlement onboard. This would not only lead to better compliance but also help alleviate several safety issues that vulnerable populations might face, especially women.

To apply the method on a large scale, software using the method described in this paper could be created. Algorithms could automate the process and find optimal solutions. Dijkstra’s algorithm, the Bellman–Ford algorithm, or similar algorithms dealing with oriented graphs and combinatorics could be used to minimise lengths of the most heavily used paths. Weighted graphs (those for which each edge is assigned a weight) could be used to reflect more crucial factors such as distances between lane intersections, the inclination of streets, sunlight at different times of the day, etc. It would be important to address less obvious issues, such as the stimulation of the local economy. By creating important circulation arteries through commercial zones within the informal settlement, it would allow for both limited disturbance near private residences and controlled access to the public marketplace. As mentioned previously, distances to basic necessities (such as public toilets, water access and waste disposal) should be minimised. Regardless of the algorithms used, it is very important to let the residents of the informal settlement participate in the process to obtain an outcome that suits their movement patterns and make them feel valued.

Once a circulation network has been mapped and the Cluster Lane Method used to assign orientations to each lane, this must be clearly communicated to the pedestrians. By installing colour-coded signs or by painting arrows on the floor, one could establish a consistent visual communication system that transcends any linguistic divide. An effective signage system would thus make it easier for pedestrians to follow the assigned orientation of each lane. To help people understand the logic of the circulation system as a whole, it would be beneficial to have three different types of arrows or signs associated with the three types of lanes discussed in section 4.1. Arrows could be placed throughout each lane, or simply at the intersections, marking the beginning and end of each lane. Additionally, maps with the assigned orientations of lanes could be distributed to the population and installed in key locations. This cost-efficient, low-tech solution would be fast to implement, would significantly reduce the number of face-to-face interactions between pedestrians and would allow for physical distancing in narrow public circulation spaces. By including the direction of lanes in navigation applications such as Google Maps, minimal routes could be determined for each walk. Eventually, pedestrians could get used to the new unidirectional circulation system.

To ensure universal accessibility and usage of the proposed circulation, it would be necessary to think of the passageways more holistically. The conditions of public circulation networks in informal settlements, which include irregular surfaces and various obstacles along paths, make it difficult for the visually impaired to navigate through them. Tactile paving (or Tengji blocks), accredited to Japanese inventor Seiichi Mikaye, is a revolutionary navigation aid for the visually impaired. It consists of tactile blocks on pavement which are:

- intended to alert visually impaired pedestrians of upcoming dangers, like sidewalk curbs and train platform edges.

(Konstantinovsky 2019)

Different tiles exist (Katsumi et al. 2008), but none seems to indicate a direction for unidirectional travel. It would be useful to design and implement a ‘unidirectional tactile paving’ with a distinctive (and possibly asymmetrical) pattern which could clearly communicate the assigned direction of a lane to the visually impaired.

6. CONCLUSIONS

The application of the Cluster Lane Method on a circulation network of an informal settlement could help reduce contagion within public circulation spaces by limiting face-to-face interactions.
between pedestrians. This is particularly useful in the context of narrow lanes with poor natural ventilation. The flexibility of the method makes it possible to adapt it to any circulation network. By studying the social behaviours within the informal settlement and by including the population in the process, a more adequate site-responsive result could be obtained.

The application of the Cluster Lane method would not reduce existing issues found in informal settlements which facilitate contagion (dense population, lack of basic sanitary infrastructure, etc.). However, this additional strategy makes the best of existing circumstances. When used in concert with other outbreak management tools such as masks, physical distancing and vaccination, unidirectional circulation has the potential to further slow the transmission of COVID-19 within informal settlements and save numerous lives.

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AUTHOR AFFILIATIONS

Juan Fernández González orcid.org/0000-0002-1587-0119
B.Sc. Architecture ’19, McGill University, Montreal, QC, Canada

Ankit Gongal orcid.org/0000-0001-5175-0328
B.Sc. Architecture ’19, McGill University, Montreal, QC, Canada

COMPETING INTERESTS

The authors have no competing interests to declare.

SUPPLEMENTAL DATA

Appendices 1 and 2 for this article can be accessed at: https://doi.org/10.5334/bc.113.s1

REFERENCES

Alexander, C., Ishikawa, S., Silverstein, M., with Jacobson, M., Fiksdahl-King, I., & Angel, S. (1977). A pattern language. Oxford University Press.

Bai, X., Nagendra, H., Shi, P., & Liu, H. (2020). Cities: Build networks and share plans to emerge stronger from COVID-19. Nature, 25 August. https://www.nature.com/articles/d41586-020-02459-2

Benjamin, A., Chartrand, G., & Zhang, P. (2015). The fascinating world of graph theory. Princeton University Press. DOI: https://doi.org/10.2307/j.ctt9qh0pv

Bhatt, V., Navarrete, J., Friedman, A., Baharoon, W., Minhui, S., Teixeira, R., & Wiedermann, S. (1990). How the other half builds. Vol. 3: The self-selection process. Centre for minimum cost housing. McGill University.

Biswas, S. (2020, June 22). How Asia’s biggest slum contained the coronavirus. BBC News. https://www.bbc.com/news/world-asia-india-53133843

Bliss, L. (2020, April 3). Mapping how cities are reclaiming street space. Bloomberg CityLab. https://www.bloomberg.com/news/articles/2020-04-03/howcoronavirus-is-reshaping-city-streets

Boo, K. (2012). Behind the beautiful forevers: Life, death, and hope in a Mumbai undercity. Random House.

Brelsford, C., Martin, T., Hand, J., & Bettencourt, L. M. A. (2018). Towards cities without slums: Typology and the spatial evolution of neighbourhoods. American Association for the Advancement of Science: Science Advances. advances.sciencemag.org/content/4/8/eaar4644/tab-pdf. DOI: https://doi.org/10.1126/sciadv.aar4644

Bulfone, T. C., Malekinejad, M., Rutherford, G. W., & Razani, N. (2020). Outdoor transmission of SARS-CoV-2 and other respiratory viruses: A systematic review. The Journal of Infectious Diseases. academic.oup.com/jid/article/223/4/550/6009483. DOI: https://doi.org/10.1093/infdis/jiaa742

CDC. (2020, July 15). Prevent getting sick: Social distancing. Centers for Disease Control and Prevention (CDC). www.cdc.gov/coronavirus/2019-ncov/prevent-getting-sick/social-distancing.html
CDC. (2021, April 19). Guidance for wearing masks: Help slow the spread of COVID-19. Centers for Disease Control and Prevention (CDC). https://www.cdc.gov/coronavirus/2019-ncov/prevent-getting-sick/cloth-face-cover-guidance.html

Dovey, J., & King, R. (2011). Forms of informality: Morphology and visibility of informal settlements. Built Environment, 37(1), 11–29. https://www.jstor.org/stable/23289768. DOI: https://doi.org/10.2148/benv.37.1.11

ECOSOC. (2020, April 28). Progress towards the Sustainable Development Goals: Report of the Secretary-General. United Nations Economic and Social Council (ECOSOC). https://unstats.un.org/sdgs/files/report/2020/secretary-general-sdg-report-2020-EN.pdf

Grasl, T., & Economou, A. (2018). Palladian graphs: Using a graph grammar to automate the Palladian grammar. ResearchGate. https://www.researchgate.net/publication/282356419

Greenhalgh, T., Jimenez, J. L., Prather, K. A., Tufekci, Z., Fisman, D., & Schooley, R. (2021). Ten scientific reasons in support of airborne transmission of SARS-CoV-2. Lancet, 397(10285), 1603–1605. DOI: https://doi.org/10.1016/S0140-6736(21)00869-2

Ingersoll, R. (2013). World architecture: A cross-cultural history, 2nd edn. Oxford University Press.

Johns Hopkins Coronavirus Resource Center. (2021, May 25). Cases by country/region/sovereignty. Johns Hopkins University & Medicine. https://coronavirus.jhu.edu/map.html

Johnson, K. (2013). Census: 1 in 6 Indian city residents lives in slums. San Diego Union-Tribune. https://www.sandiegouniontribune.com/sdut-census-1-in-6-indiacy-residents-lives-in-slums-2013mar22-story.html

Jordan, H. (1994). Public parks, 1885–1914. Garden History, 22(1), 85–113. DOI: https://doi.org/10.2307/1587004

Katsumi, T., Tomomi, M., Arisa, N., Kunijiro, A., & Mayumi, A. (2008). Guidebook for the proper installation of tactile ground surface indicator (braille blocks): Common installation errors. International Association of Traffic and Safety Sciences.

Konstantinovsky, M. (2019, March 18). Seiichi Miyake created tactile paving system to help visually impaired. How Stuff Works: Science. https://science.howstuffworks.com/engineering/civil/seiichi-miyake-tactile-pavingsystem-visually-impaired.htm

Maragakis, L. L. (2020, July 15). Coronavirus, social and physical distancing and self-quarantine. Johns Hopkins Medicine: Health. https://www.hopkinsmedicine.org/health/conditions-and-diseases/coronavirus/coronavirus-social-distancing-and-self-quarantine

March, L., & Steadman, P. (1974). The geometry of environment: An introduction to spatial organization in design. MIT Press.

McDougall, M. (2007, March 4). Waste not, want not in the £700m slum. The Guardian. https://www.theguardian.com/environment/2007/mar/04/india.recycling

Morawska, L., & Milton, D. K. (2020). It is time to address airborne transmission of Coronavirus disease 2019 (COVID-19). Clinical Infectious Diseases, 71(9), 2311–2313. DOI: https://doi.org/10.1093/cid/ciaa939

Public Services and Procurement Canada. (2020, June 22). Guidance and practices for the safe return to workplaces in light of the easing of restrictions. Government of Canada. https://www.canada.ca/en/government/publicservice/covid-19/easing-restrictions/departemental-guidebook/return-workplace-covid-19.html

Romero, V., Stone, W. D., & Ford, J. D. (2020). COVID-19 indoor exposure levels: An analysis of foot traffic scenarios within an academic building. Transportation Research Interdisciplinary Perspectives, 7, 100185. DOI: https://doi.org/10.1016/j.trip.2020.100185

Trading Economics. (2020). Brazil—Population living in slums. Trading Economics. https://tradingeconomics.com/brazil/population-living-in-slums-percent-of-urbanpopulation-wb-data.html

Vardouli, T. (2017). Graphing theory: New mathematics, design, and the participatory turn. MIT Libraries. https://dspace.mit.edu/handle/1721.1/113917

Weissine, E. W. (2020a). Four-color theorem. Wolfram MathWorld. https://mathworld.wolfram.com/Four-ColorTheorem.html

Weissine, E. W. (2020b). Polyhedral formula. Wolfram MathWorld. https://mathworld.wolfram.com/PolyhedralFormula.html

WHO. (2021, April 30). Coronavirus disease (COVID-19): How is it transmitted? World Health Organization (WHO). https://www.who.int/news-room/q-a-detail/coronavirus-disease-covid-19-how-is-it-transmitted

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