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Arguments for building The Circle and not The Line in Saudi Arabia

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Saudi Arabia plans to construct a new city, home to 9 million people. The most relevant aspect is its form, a line with a surprising length of 170 km. We analyse whether this is the best plan for a new city and some inconveniences of the prolonged urban form.

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PLANNING A LINEAR CITY

Something is fascinating about the idea of planning and building a large city from scratch. All issues about city planning that we suffer daily could be fixed if we started things all over again. Cities like Brasilia or Abuja are precisely that. A city that was planned from the beginning with the idea of hosting millions of people within only a few years. Unlike cities that grow organically and where it takes decades to reach a large population, a planned city sets a goal for its people and purpose. Despite a long history, the reception of planned cities, especially large-scale projects, has been mixed, with implementations often falling behind the initially set goals or being riddled with unforeseen problems[1–3]. A highly ambitious project for a new planned city is The Line, Saudi Arabia, which started its excavation works in October 2022. It aims to host 9 million residents in a footprint of only 34 km^2. Unlike any other city, The Line is conceptually a straight line stretching from the Red Sea, 170 km East. The whole city is planned to be composed of two unbroken lines of 500 m high skyscrapers and a width of 200 m. The buildings in The Line will be taller than the Empire State Building and all constructions in Europe, Africa and Latin America. The Line will have 265,000 people per km^2, about ten times the residential density of Manhattan and four times the density of Manila, considered one of the most densely populated cities on Earth[4]. The city is planned to be incredibly long, extremely tall, and surprisingly dense.

Certain aspects of The Line are shared with many plans for new developments, such as being smart, having a high-speed rail system and depending on artificial intelligence and data-sharing models among its population. What makes The Line unique is its form. In context, 170 km is the distance between Pisa on one side of Italy and Rávena on the other (Fig. 1a). Distances on The Line cannot be neglected. Although it is not the first time that a straight line is conceived as the shape of some urban area, it is the first time that construction at such a scale is taking place[3].

There are some positive aspects of The Line. Sustainability is emphasised in many aspects of the project. It will be constructed around a high-speed rail, considering mobility as a core part of the city. It is set to have zero cars with services reachable within a five-min walk. In a city without cars, a lot of space for parking and infrastructure is saved. All energy will be produced with zero carbon emissions. The Line is set to have roughly the same population as the metropolitan area of Johannesburg but occupies only 2% of its surface. Having a minimal urban footprint is touted as contributing significantly to The Line being an example of a green and sustainable city. Nevertheless, it raises questions on the livability and technologies required to achieve this and their real environmental impact. Thus, we should seriously consider whether the truly unique attribute of The Line —its form—is the best shape for a new city. We note that there are other possible reasons for choosing this unique form, such as the creation of a unique identity that will create and reinforce a status of Global City for The Line[5]. However, it is important to understand the impact of this choice on sustainability outcomes, especially if The Line is expected to have a global impact as a showcase of modern construction and city planning technologies.

CITY FUNCTION AND CONNECTIVITY

There have been many attempts to define what a city fundamentally is. Cities are complex landscapes for interaction among diverse individuals, ideas and activities that embody the principle that the whole is more than the sum of its parts. What differentiates a city from smaller settlements is not only the size but that such dimensions provide more possibilities for interactions and more opportunities for its residents. This principle is sometimes formulated in terms of superlinear scaling laws[6], but applies more generally. However, this requires *connectivity*, i.e., that residents can easily reach many parts of a city. A city of 9 million people might support several specialised businesses and institutions catering to uncommon interests (e.g. workshops or art galleries), but only if their customers and employees can reach them in their commute. Several cities aim to achieve more sustainable outcomes by establishing *15-minute neighbourhoods* (or similar concepts), where residents' services are reachable within short distances via active mobility. This is a laudable goal that can matter greatly in solving transportation-related issues by avoiding unnecessary long trips. However, a city offers more to its residents than what is simply available in their immediate neighbourhood. While it is undoubtedly an excellent direction to ensure that everyday services are accessible via a short walk, a city of sufficient size will offer additional services that cater to only a small part of the population (or a small part of the population on any specific day, such as a music concert), and thus cannot be located close to all of them. The same principle applies to employment as well. While it is desirable to have one's job within walking distance from home, a big city offers the opportunity to look for employment outside a limited neighbourhood. Thus, it is vital to investigate the share of a city that is reachable for any of its residents beyond their immediate neighbourhood. The Line aims to address all of these by having an extremely high density,

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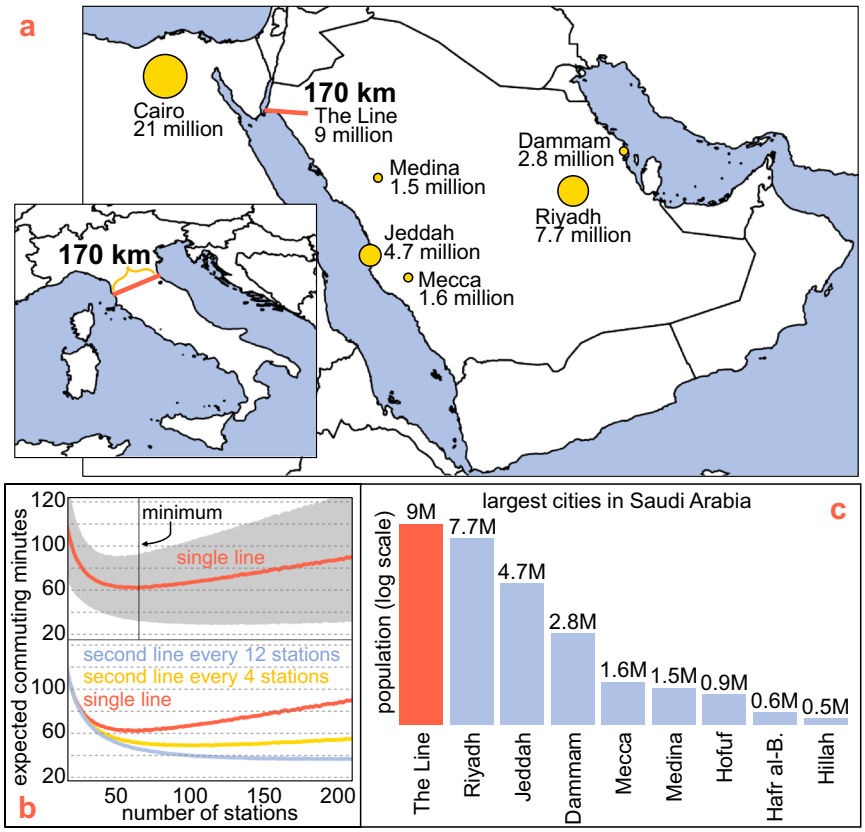

Fig. 1 Plan for The Line in Saudi Arabia. a Location of The Line in Saudi Arabia. **b** Expected commuting time (vertical) depending on the number of stations (horizontal) with a single high-speed train line (top) and a combination of local and express services (bottom). The commute was estimated by randomly considering pairs of origin and destination for each trip and computing the time required to walk to a station (which depends on the location of the origin and the number of stations), wait for a train (60 s), move between stations (considering an acceleration or retardation of 1 m s^{-2} and 20 s at each station), and the time required to walk from the station to the destination. The interval was computed by removing the top and bottom 10% of the time needed, thinking that journeys across the whole city would not be frequent. **c** Largest cities in Saudi Arabia, including the planned population of The Line.

featuring mixed-use development and thus services reachable via walking. However, it is yet unclear if the unusual shape contributes toward or against reaching these goals.

Efficient transportation plays a key role in the success of cities, and governments worldwide struggle to provide the infrastructure that their cities require to thrive. While cities come in many shapes and sizes, research shows that people prefer to spend a similar, limited amount of time commuting, regardless of the distance[7]. Long commuting time reduces residents' quality of life, while transportation-related externalities account for a significant portion of the environmental footprint of urban residents[8]. While commute time is the main factor for residents, the length and mode of commute are highly significant for urban sustainability. Shorter commutes and encouraging active mobility and public transport have recently become crucial public policy goals. Achievement of such goals depends to a large extent on urban form, both macro-level measures (density, shape), meso-level features (land use patterns) and micro-level interventions (walkability, microclimate).

One of the most critical aspects related to The Line is distance. If its 9 million inhabitants are homogeneously distributed in the city, each km will have roughly 53,000 people. If we randomly pick two people from the city, they will be, on average, 57 km apart. Although The Line occupies only 2% of the surface of Johannesburg, if we pick two random people in Johannesburg, they are only 33 km apart[9]. Keeping the surface fixed, a line is the contiguous urban form that maximises the distance between its inhabitants. In The Line, people are as far away from others as possible. Considering that a walkable distance is 1.0 km[10], in The Line, only 1.2% of the population is at walking distance from others. Active mobility is not viable in The Line since distances are too long. The plan for The Line has no cars but also gets rid of most active mobility. Although in The Line, basic needs could be satisfied within 5 min, most journeys to school, work, leisure or visiting other people will depend on public transport (details in Supplementary information).

The real challenge in The Line is achieving long-distance transportation to allow interconnectedness on a large scale. The Line needs at least 86 train stations to guarantee that everyone is within walking distance of a station. But with so many stations, trains stop too frequently, reducing their average speed and spending too much time at stations. Travelling from one random location of The Line to the other will take, on average, at least 60 min, including walking to and from a station, waiting for the next service and riding a train that frequently stops (Fig. 1b). With only 86 stations, people will have to walk from their origin to the nearest station, on average, more than 1.3 km for each journey (nearly 18 min), more time than most people are willing to walk. Increasing the number of stations reduces the time required to reach the system but increases the requirement for dropping off passengers. Regardless of the number of stations on The Line, at least 47% of the population will have a commute longer than 60 min so most people will live too far from their destination. A highly modular and hierarchical transportation system with seamless transfers among local and express lines is needed, consisting of a mixture of high-speed trains and more local

services. However, additional infrastructure has diminishing returns (Fig. 1b). The population of The Line will experience higher commuting times than much bigger cities, such as Seoul, where 25 million people within its metropolitan area experience a commute below 50 min[11]. More details are in the Supplementary information.

THE CIRCLE, ANOTHER URBAN FORM

Imagine that instead of a line, we take the buildings that will be constructed in that city and we arrange them differently. Like playing with Lego bricks. We can think of a city called The Circle, where we take the same tall buildings as in The Line but put them next to each other, forming a circular shape. A circle that occupies the same surface as The Line (34 km^2) has a radius of only 3.3 km. In The Circle, the expected distance between two random people is only 2.9 km. In The Circle, a person is at a walking distance of 24% of the population (and within 2 km, they could reach 66% of the destinations), so most of their mobility could be active. In The Circle, a high-speed rail system is unnecessary since people could walk or cycle to most places, and buses could supply the rest of the journeys. The Circle occupies roughly the same surface as Pisa, Italy, but has 50 times its population. A round urban form is the most desirable since it reduces commuting distances and the energy required for transport[9].

Building The Circle on such a scale might seem even more challenging than building The Line, mainly due to issues of light and ventilation created by the tall buildings. However, by changing the shape, we can achieve greater flexibility when considering the trade-offs between density and connectedness. In The Line, a person willing to walk 1 km can reach 106,000 people. Requiring the same number to be reachable in a circular city requires a density of only 33,740 people per km^2, i.e., a density only 25% higher than Manhattan. The Circle achieves similar easily reachable neighbourhoods but relies on significantly lower densities—in fact, requiring only densities achievable with well-established building technologies. Then, we should construct The Circle and not The Line. Mathematically, while The Line is essentially a one-dimensional city, The Circle is two-dimensional. In one dimension, the number of reachable places scales linearly with distance, whereas in the two-dimensional case, the scaling is quadratic. In The Circle, by travelling twice as far, one can reach four times as many different places.

AMBITIOUS POPULATION GROWTH

One of The Line's challenges is its ambitious population size. Saudi Arabia has 36.7 million people in 2023, and including births, deaths and migration to and from other countries, it will have an additional nine million inhabitants by 2043[12]. In the next two decades, Saudi Arabia will grow by roughly nine million people. That means that attracting nine million people to The Line implies that the remaining cities in the country should be very close to their peak population by now. The Line has to capture most population growth from the country to reach its planned population and become even larger than Riyadh, the country's capital (Fig. 1c). But how to attract such a vast population in a medium-sized country is yet to be observed.

Furthermore, reaching a population above or below nine million inhabitants would also be quite challenging. On the one side, a smaller population would imply infrastructure that has been constructed used below its capacity. Reaching fewer people within walking distance and fewer public transport users. But, on the other side, a bigger population is even more challenging. As with Brasilia (which was planned to have less than 20% of its current population), the city has minimal room for expansion. Further vertical growth or increasing the city's density is impossible, and relaxing its restriction of being on a line defeats its purpose. Thus, the city can only grow further East, increasing its length and further exacerbating the transportation problems discussed above.

Other challenges are also part of The Line. Building tall skyscrapers requires a lot of materials and energy, and tall buildings have greater exposure to stronger winds, solar gains and extreme temperatures and rely heavily on artificial lighting[13,14]. In such a vertical development, the energy consumed by elevators and the delays they create is not negligible[15]. While The Line has the laudable goal of providing all energy from renewable sources, the feasibility of this scheme will depend on the energy efficiencies achieved. Beyond operational energy use that has in the past dominated total energy requirements of buildings, a significant concern is the embodied energy requirement during construction, which can represent the majority of energy and environmental impact for modern construction[14]. It has been shown that embodied energy requirements scale non-linearly with building height[16–18], and that medium-height buildings can be optimal when considering the combined environmental impacts[19]. Using a circular shape would require significantly lower density and building height while providing similar connectivity to residents.

Beyond environmental issues, we further note that a linear system forms the most vulnerable type of network, meaning that the transport system is susceptible to failures, for example, fire in any of the stations, potentially leaving most people static. Thus, any accident or failure in the transport stations could paralyse a substantial part of the city. While The Line is an ambitious project, using a more conventional shape for a city, it is possible to obtain significantly lower densities and achieve similar walkability and better connectivity without issues in the transportation system.

Reporting summary

Further information on research design is available in the Nature Research Reporting Summary linked to this article.

DATA AVAILABILITY

The analysis for this article did not use any datasets. Script for reproducing the results and Fig. 1 are available at https://github.com/rafaelprietocuriel/TheLine.

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COMPETING INTERESTS

The authors declare no competing interests.

ADDITIONAL INFORMATION

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