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MSc. Integrated Urbanism and Sustainable Design

Healing the city

Exploring the spatial determinants of tuberculosis in the slums of Lima

Master Thesis by

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Abstract

Tuberculosis (TB) has been ranked as the top infectious deathly disease worldwide. In the Americas, the second-highest incidence of TB is found in Peru, which concentrates most of its cases in Lima. Affected people in working ages are usually living in economic poverty, and are hindered from having healthy social and working lives. Current plans to stop the epidemic are strongly focused on biomedical strategies, which seem to be ineffective in reducing the prevalence towards reaching the aim of ending TB by 2035. Further challenges of rapid urbanization could worsen the problem if no bold measures are taken by the actors involved.

This research intends to profile the determinants, which play an essential role in the transmission of TB in endemic slums, through the exploration of spatial characteristics in the affected households and the linkage with the factors and scientific evidence around high transmission settings. The study was conducted in two neighborhoods which can be considered as paradigmatic examples of the informal urban development processes in Lima, which at the same time are endemic areas of TB: 'Barrios Altos' and 'San Cosme' Hill. The latter have essential differences in their urban forms and historical backgrounds; nevertheless, they are taken as representative samples of the diverse morphology within the slums in Lima. The inquiry outlines direct relations of the physical conditions with exposure and environmental factors for TB transmission, and points out the specific high-risk settings, suggesting that improving such conditions could have potential benefits for the health of residents. Suitable solutions for the epidemic are proposed through physical upgrading, implying changes in the current approach, policies, and actions to achieve socio-economic development. Multi-level and multi-sectoral strategies are needed towards the construction of healthier neighborhoods in Lima, avoiding hygienist postures, forced evictions, and gentrification.

Keywords: slums, tuberculosis, built environment, spatial conditions, upgrading, public health, urban form, housing

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1. Introduction

Infectious diseases have long been related to urban agglomerations. Early industrialization processes in the global north resulted in explosive urbanization and population increase, which exceeded public management capacities. Social issues, poor living conditions, and disease epidemics like cholera and tuberculosis added heavy burdens to low-income migrants and working classes. In that context of political instability and social discontent, the responses from public health workers sought to address with urgency the improvement and organization of the built environment, driving the creation of the urban planning discipline.

Diseases attributed to the built environment are no longer the most onerous burden in the global north. In recent years, however, urbanization processes had speed up around the world, presenting perhaps one of the biggest challenges humankind has ever faced: by 2050, seven out of every ten people will live in urban settings. The pace of this process results in severe problems for cities, especially in the developing world, which cannot respond effectively to the increasing demands of newcomers seeking for better opportunities. In that context, less-advantaged migrants can survive only by creating their dwellings in any available spaces in the inner city or its outskirts, resulting in the creation of informal settlements. The poor living conditions in most of the slums and shantytowns consequently affect the mental and physical health of their dwellers, adding an extra burden to the social problems of unemployment and social exclusion.

Problems of the past seem to repeat in the present. Infectious diseases like TB are still epidemics in deprived urban areas of developing countries, where biological, social, and environmental factors are put together to create fostering conditions for transmission. Among the burden in American countries, Peru carries one of the heaviest ones with an alarming concentration of cases in the capital city. TB costs are expensive and have social and economic repercussions for all sectors of Peruvian society and international agents. Recent efforts which intend to respond to broader strategies recommended by the WHO and PAHO, seem not to be effective in reducing the incidence towards the goal of ending TB by 2030. In Peru, a strong focus on the biomedical approach in the struggle against TB seems to be prevalent over social efforts, and measures to tackle environmental determinants are generally restricted to awareness-raising.

The role of the built environment in TB epidemics has been generally described throughout history; however, the specific factors in present slums are yet to be fully understood. The geographical distribution of the disease in Lima unveils high prevalence in 'Central Lima', northern and eastern peripheries, which coincidently have a population with low socioeconomic status. The focus of this inquiry is in two neighborhoods which underwent the process of internal migration during the first half of the 20th century and could be considered as paradigmatic examples of the slums in 'Central' and 'peripheral' Lima. Thus, this research seeks to describe the spatial characteristics related to TB transmission, to demonstrate the relevance of the built environment as an essential factor to complete the equation towards suitable and sensible solutions within the present context to end the burden of TB in Peru.

1.1. Research aim and objectives

In Peru, the struggle against TB appears to be strongly focused on biomedical solutions, supported by small actions of social aid. Also, measures in the built environment are limited to prevention awareness advocated by the health sector, whereas TB incidence decrease seems to be insufficient to meet the goal of ending TB by 2030. In that context, bold measures could be needed to create more effective strategies, especially for endemic areas which coincidently are slums. Considering the context of Lima, the capital city of Peru, this research aims to explore the spatial determinants of TB to understand the role of the built environment where the affected dwell, and outline the implications of possible actions to improve their health outcomes.

Through literature review and measurement and analysis of data gathered in the field, the following objectives should be met to achieve the aim of this inquiry:

- Understand the urban challenges related to TB;
- Understand the mechanisms of TB transmission and prevention;
- Analyze the possible implications of the application of preventive measures in the built environment of slums;
- Understand the urban development processes of the cases study in Lima;
- To analyze the characteristics of the built environment where the affected dwell concerning the factors of TB transmission;
- To propose recommendations to inform the sectors involved.

1.2. Research questions

The scope of this research is narrowed down to the analysis of slum housing in Lima and the internal and external factors which could influence TB transmission. Therefore, the main research question this inquiry attempts to answer is:

"How are slum houses contributing to TB transmission in Lima?"

In order to support the investigation, the following questions are formulated:

- How is TB transmitted?
- Which are the determinants for TB transmission in relation to housing?

- How can the spatial characteristics of a slum in different scales influence on TB transmission?
- How can MTB infection be prevented in slum houses?
- Which are the implications of applying preventive measures in slums?

1.3. Research Methodology

This research was carried out in five steps with different outcomes, which supported the following steps:

- Theoretical framework: the research questions regarding the role of the built environment in TB transmission, preventive measures, and the possible repercussions are answered through literature review and expert interviews. This step gives data based on scientific and empirical evidence for the next one.
- Tools for research visit: physical characteristics related to high-risk transmission settings were identified, and used as a base to create the material for the field research visit.
- Field research visit: during two months, several visits were made to affected households in the case study neighborhoods, where observation and evaluation of the housing and its surroundings were carried out. Additional data was gathered based on structured interviews to support the findings.
- Data analysis: the outcomes of the previous steps were analyzed to identify patterns of spatial characteristics related to high-risk settings in the study areas, and profile them for the discussion.
- Proposal of recommendations: in this part, possible preventive and improvement measures are proposed, and their implications are discussed for urban practitioners, authorities, and other sectors involved.

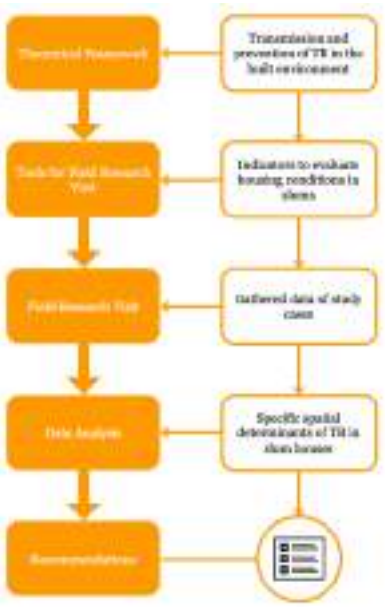

Figure 1: Diagram of research methodology. Source: the author.

2. The burden of TB

2.1. Brief history of TB

Researchers estimate the earliest traces of MTB back to 3 million years ago in East Africa, and found DNA traces and symptoms on ancient Egyptian mummies from approximately 5000 years ago. It is assumed that MTB was taken to Asia and Europe with early human migration waves, though its inclusion in the Americas could had been delayed by the presence of the Bering Strait (Daniel, 2000). Nevertheless and similarly as the evidence found in Egypt, MTB has been found in Peruvian mummies of aboriginal cultures which existed before the contact with the Europeans in the XIV century (Daniel, 2006, pp. 1862–1864). A recent study suggests that a strain of TB reached south America during precolonial times, carried by seals which traveled from Africa through the sea. The infection to humans could had happen through direct contact with these mammals and consumption of their meat for ritualistic purposes (Bos et al., 2014).

The spread of TB in other parts of the world is confirmed by documentations in Ancient Greek, Indian and Chinese civilizations. Similar evidence lacked in medieval Europe, nevertheless, the archeological studies corroborate the existence of widespread areas in the continent (Daniel, 2006, p. 1863). Measures for epidemiological control were taken during renaissance in Italy, through the isolation of the affected and the establishment of places for their treatment (Barberis et al., 2017). Later in the 18th century, the industrial revolution marked the beginning of a new phenomenon of chain effects originated with massive rural-urban migration to cities, which resulted in the deterioration of living conditions within the poor, and outbreaks of infectious diseases like TB (Barberis et al., 2017; Godfrey and Julien, 2005).

Figure 2: Slum in Paris 1872. Source: NY Times, 2014.

In Europe and North America during the early 19th century, TB epidemic increased alarmingly. Human loses were calculated around 800 to 1000/100'000 people per year in European cities like Hamburg, Stockholm and London (Daniel, 2006, p. 1864), in a period when further industrial development accelerated urbanization and increased population rates exponentially (Barton et al., 2015, p. 48). Around 1860, hygienist movements and the development of Public Health started in Britain, tracing firmly the role of the built environment on negative health outcomes, and promoting slum clearance and housing provision as control measure among citizenry (Godfrey and Julien, 2005). Parallelly, the generalized belief that fresh air and sunlight had a regenerative effect on health, shaped awareness campaigns and determined the design principles of sanatoria specialized for the treatment of TB (Campbell, 2005; Daniel, 2006, p. 1866). The aim of sanatorium residence was to isolate the affected from other susceptible subjects, to follow strict hygienic practices in contact with nature. Weather if sanatoria were effective on relieving people from the illness is unclear, however there was evidence that death rates were lower than other patients treated at home (Daniel, 2006, p. 1866).

A gradual decrease in mortality rates, was noted since the early and mid-19th century, which can be attributed to different factors, yet none of them explain clearly the reasons for that decrease. Among the possible explanations are the improvement of living conditions, improved nutrition of the population, and development of resistance to infection through natural selection (Davies RPO et al., 1999). In 1882, Herman Heinrich Robert Koch identified the bacillus, unveiling further possibilities for cures after centuries of medical struggle and experimentations (Daniel, 2006). The enhancement of detection techniques, the development of the BCG vaccine (Bacille Calmette-Guérin) for children, and other advances on antibiotics, could have influenced a gradual switch on the control strategies towards biomedical solutions.

2.2. Global challenge of TB

Tuberculosis (TB) in developed countries are today at their historical lowest points, yet it remains being a heavy burden especially for the countries in the global south. In 2017, TB caused 1.6 million deaths becoming the worldwide top infectious deathly disease from a single infectious agent (WHO, 2018a, p. 1). Moreover, 23% of the total population on earth are estimated to have latent TB infection (LTBI), and 5-10% of them are at risk of developing active TB (WHO, 2018a). The recent sprout of drug resistant TB (MDR-TB and XDR-TB) is challenging the current biomedical efforts and increases the expenditure of control strategies. Two thirds of the global burden is located in eight countries: India, China, Indonesia, the Philippines, Pakistan, Nigeria, Bangladesh and South Africa (WHO, 2018b). HIV is a key determinant to develop active TB, the highest rates of this comorbidity are located in Sub-Saharan African countries.

A possible explanation for the uneven distribution of TB is the prevalence of global structural socioeconomic determinants, which include high levels of population mobility, rapid urbanization, and population growth (Hargreaves et al., 2011). These contribute to food insecurity and malnutrition, poor housing and environmental conditions, financial, geographic and cultural barriers to health care access, which can increase the likelihood of disease (Hargreaves et al., 2011). The main determinant associated with TB is poverty (Silver, 1987, p. 84), which exposes the urban poor to different conditions with further negative outcomes in health (Harpham, 2009), which coincidently can contribute to develop active TB (WHO, 2018b). Likewise, environmental conditions including crowding, lack of ventilation and sunlight, have been long linked with transmission (Koch, 1901).

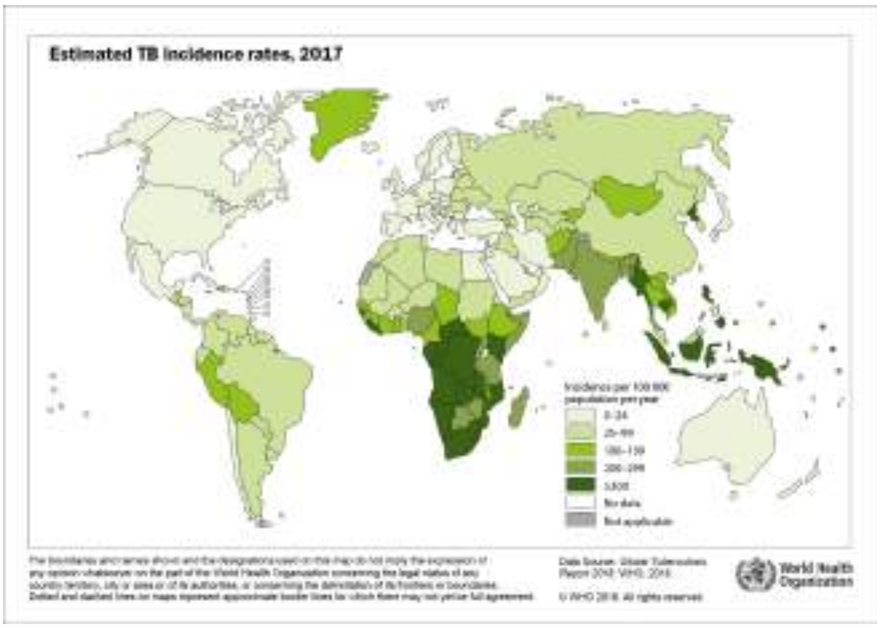

Figure 3: TB incidence rates worldwide in 2017. Source: WHO, 2018.

Since TB was declared a global public health emergency by the WHO in 1993 several efforts, campaigns, and plans have helped to accelerate the expansion of treatment and control globally (WHO, 2015). In 2015, under the SDG 3 "Ensure healthy lives and promote well-being for all at all ages", the WHO launched the 'End TB Strategy' with the vision having "a world free of tuberculosis by 2030" (WHO, 2015). Recent global reports on the epidemic state that while TB is decreasing globally, the rates are not high enough to reach the goal by 2030. Therefore, the 'End TB Strategy' pursues for more integrative and multi-sectoral approaches through expanding care, strengthening prevention and intensifying research (WHO, 2015), meaning that the role of the social determinants of TB are receiving further attention than before (Hargreaves et al., 2011). The implications of this approach are clarified by the WHO (WHO, 2015):

"Ending the tuberculosis epidemic will require further expansion of the scope and reach of interventions for tuberculosis care and prevention; institution of systems and policies to *create an enabling environment and share responsibilities; and aggressive pursuit of research and innovation to promote development and use of new tools for tuberculosis care and prevention."*

2.3. TB in Lima

In the Americas, Peru is the second country with the highest incidence of TB after Haiti. A remarkable aspect probably related with the levels of incidence, is the high levels of urbanization. From more than 32 million Peruvians, 25 million (77.9%) live in the urban areas and 34.2% of the population of the country live in slums (UN MDGs, 2015). Consequently, the highest quantity of urban population (32%) lives in Lima (UN, 2018), from which approximately 50% (around 4 million people) was living in slums by 2007 (Calderón et al., 2015), therefore exposed to conditions and deprivations which could determine their health outcomes. Coincidentally, Lima concentrates 61.29% of the total people below the poverty line of the country (INEI, 2017), 58% of the cases of TB, and 82% of the cases of MDR-TB by 2010 (MINSA, 2010, p. 16).

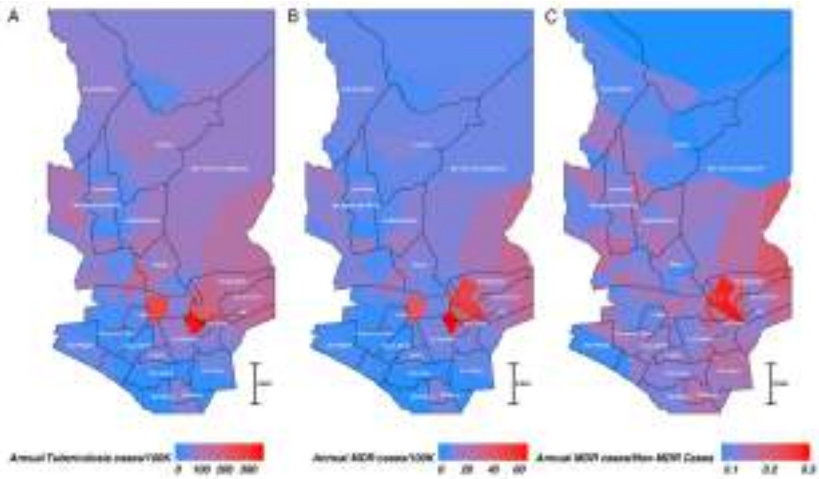

Figure 4: Map of susceptible TB and MDR-TB cases reported at health center level. Source: Zelner et al., 2016.

Additionally, the lack of affordable housing alternatives for the rural-urban economic migrants, forces those who seek new opportunities in Lima to live in slums, which are commonly the cheapest options available in the market (Meng and Hall, 2006). In such environments they are exposed to contagion of TB, as some of these areas have high incidence of the disease. Figure 3 shows the spatial distribution of TB in Lima and clustering of cases in the central and northeastern parts in red (Zelner et al., 2016), which coincidently are low-income neighborhoods. It has been calculated that affected live in crowded households inhabited by 5 to 12 members and 20% of those have bedrooms shared by 3 or more members (MINSA, 2010). Moreover, the lack of ventilation is another determinant for the disease: 40% of TB affected live in houses with at least one bedroom without window (MINSA, 2010).

On the other side, deficient health service infrastructure to attend cases of TB was reported by health workers and the lack of personal identifications of the affected prevent their access to health care system and health insurance (Integrated Health Service), which is also low (42%) among them (MINSA, 2010).

Social and economic costs of TB

The most common social group affected are economically active people between 20 to 59 years of age. Once diagnosed, TB affected have to start the treatment and stop any energy demanding activity in order to recover. In such conditions, they are hindered from a normal working and social life, and consequently to have any economic income to support themselves or their families. In some cases this requirement forces them to hide their illness and continue their working activities, thus exposing others to contagion. The patients are expected to follow from 6 to 24 months of continuous treatment to be cured, depending on the type of TB. Moreover, the stigmatization of the disease affects the individuals and their families, whom might be subjected to exclusion in their social circles.

Therefore, the economic and social burden of the struggle against TB in the country is enormous. By 2010 in Peru 80 000 million USD dollars (70 000 million EUR) were spent directly and indirectly by all sectors of society, meaning the State, the affected families and the civic sector. During that year more than one thousand lives were lost to TB (MINSA, 2010).

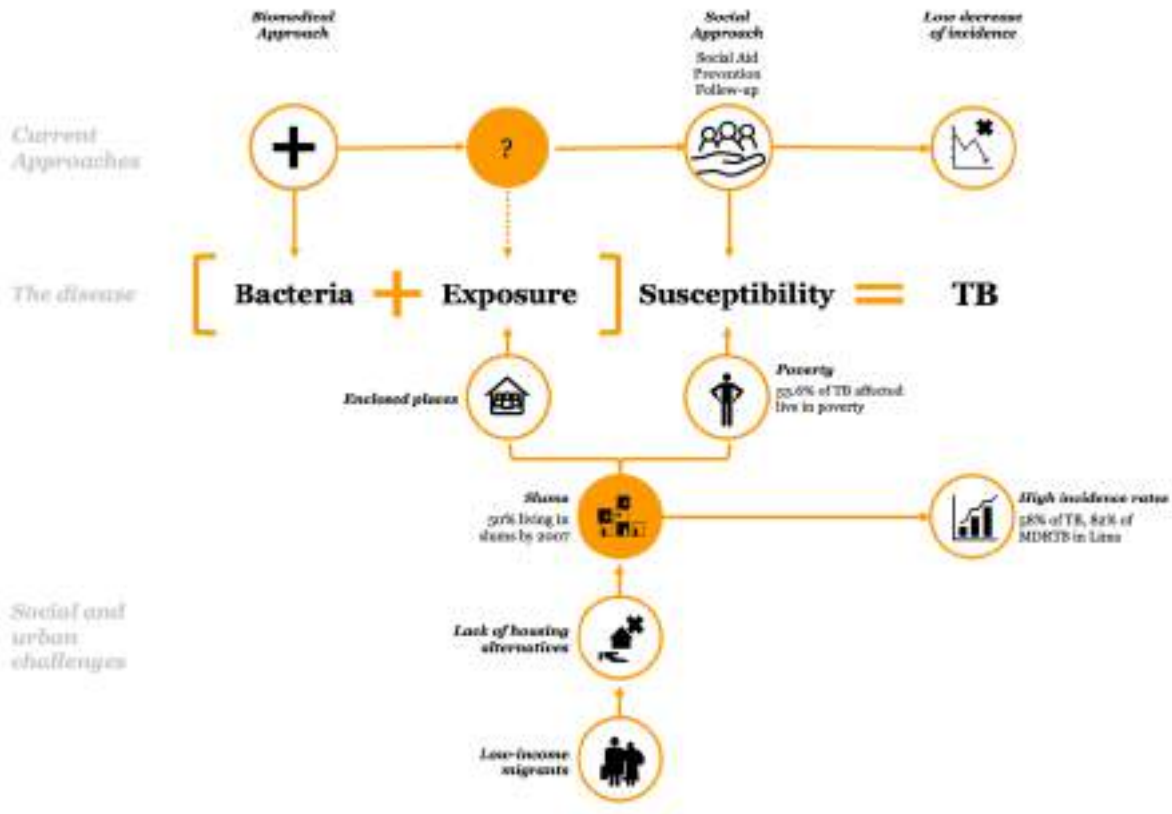

Figure 5: Diagram of the current challenge of TB in Lima. Source: the author.

Current approaches of the Peruvian government and civil society

The Peruvian government has developed a contingence plan, providing free treatment for TB and distributing free basic food packages to the less advantaged. One of its latest efforts, the "TBCero" project, is understood as an "integrative approach" which follows a socio-political line instead of a biomedical one (Fuentes-Tafur et al., 2012). This and previous plans have not decreased the incidence of TB in the rates the WHO stated for the worldwide control of the disease (Jave, 2018). Likewise, the project does not acknowledge the built environment as a determinant for TB, thus not including physical upgrading programs for the living environments of the affected among its development proposals.

3. TB Transmission and prevention

3.1. Definition of TB

Tuberculosis (TB) is an infectious disease originated by the bacteria Mycobacterium Tuberculosis (MTB). Bacilli could affect the lungs to develop pulmonary TB, or any other part of the body to result in extrapulmonary TB (WHO, 2018a, p. 6). Infection could provoke two conditions, depending mainly on the immune system status of the subject: Latent TB infection (LTBI) and Active TB disease. LTBI happens when the immune system is able to stop MTB multiplication and avoid the development of active TB, thus showing no symptoms and being incapable of transmission. Nonetheless, people with LTBI have 5 to 10% risk of developing active TB (AAOS and ACEP, 2012, p. 39).

On the other side, there is greater risk for active TB to be developed when the infected subject is immunocompromised, i.e. when having HIV or being exposed to other risk factors like diabetes, undernourishment, smoking and alcohol consume (AAOS and ACEP, 2012, p. 39; WHO, 2018a, p. 6). A person with active TB is able to spread the bacteria to susceptible subjects through specific mechanisms and settings which will be explained in the next section.

3.2. Understanding TB transmission

TB is an airborne disease. An affected person with active TB can spread MTB by expelling droplet nuclei when coughing, sneezing, talking or singing. Any susceptible subject exposed to these events can inhale the nuclei or small particles and have MTB settled in their respiratory system, resulting in infection (AAOS and ACEP, 2012; Bozzi et al., 1994, p. 39; Hobday and Dancer, 2013, p. 276; WHO, 1988, pp. 138, 140).

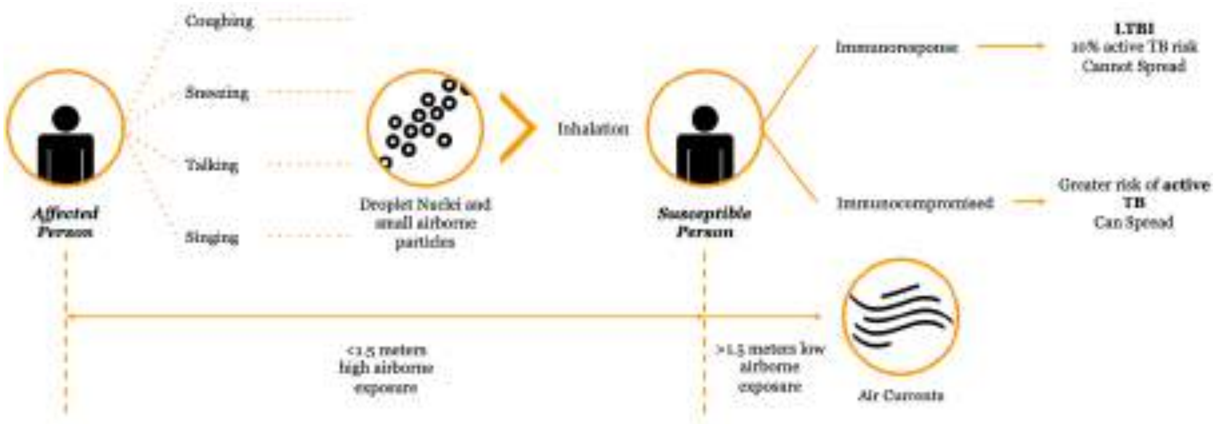

Figure 6: Transmission of MTB. Source: the author, based on (AAOS and ACEP, 2012; Bozzi et al., 1994; Forum on Microbial Threats et al., 2018)

The likelihood of infection will depend on several factors: susceptibility of the exposed individual, infectiousness of the TB affected, the environmental characteristics where contact happens, and the conditions of the exposure (CDC, 2013, p. 22). Environmental and/or exposure factors can be found in some settings which host activities and/or present physical characteristics which make them more prone for TB transmission, i.e. prisons, churches, bars, mines, classrooms, health centers, households, workplaces, public transport and slums (Churchyard et al., 2017, p. 31; Mathema et al., 2017, p. 648).

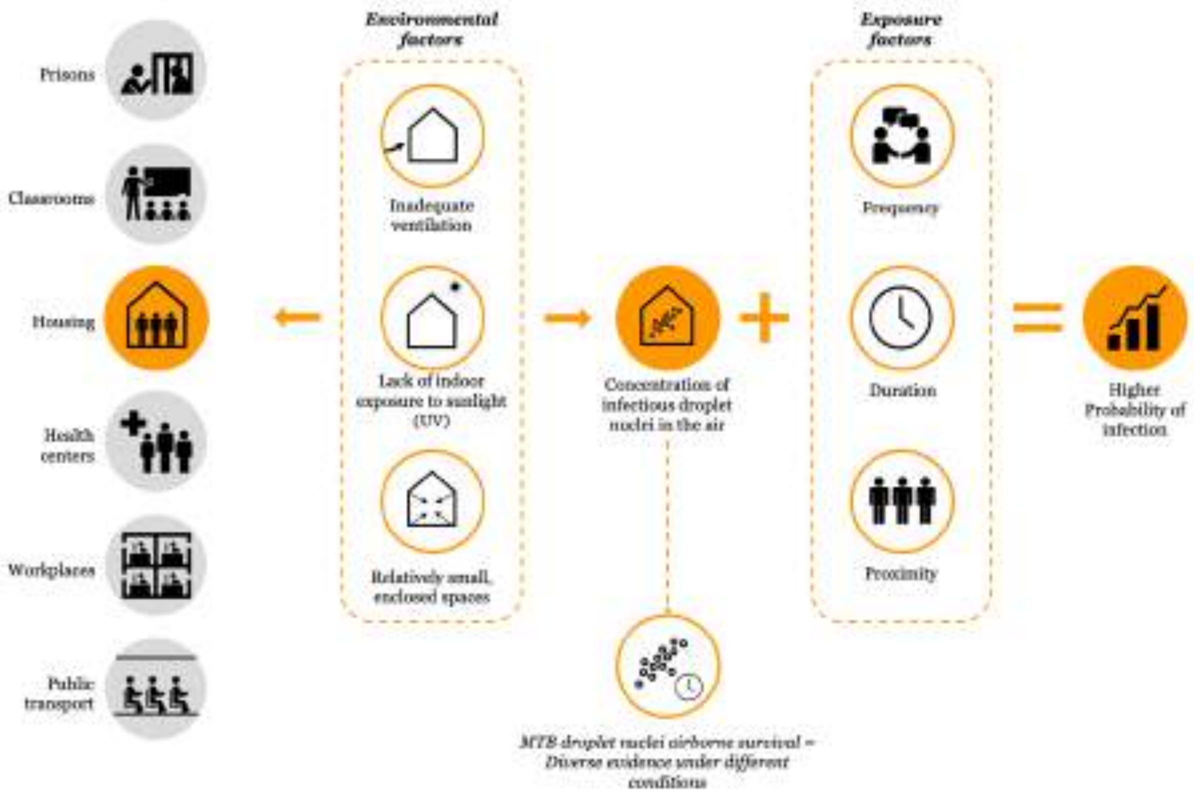

Figure 7: Environmental and exposure factors which increase the risk of transmission. Source: author, based on Bozzi et al., 1994; CDC, 2013; Churchyard et al., 2017.

3.2.1. Environmental factors

About 19% of most of the total TB burden worldwide has been attributed to environmental factors (Prüss-Üstün and Corvalán, 2006, p. 43). Additionally, TB transmission is widely assumed to be an indoor event (Hobday and Dancer, 2013, p. 274). Indoor spaces could influence the probability of contagion by presenting environmental conditions that could affect the concentration of pathogens, i.e. influencing the time that MTB could remain airborne after propelled by the affected, which could be minutes, hours, days or even months (CDC, 2013, p. 22; WHO, 1988, p. 140). Therefore, it can be said that the risk of infection will increase when contact within an affected and a susceptible subject happens in enclosed spaces, with inadequate ventilation and lack of indoor exposure to sunlight (Bozzi et al., 1994; CDC, 2013, p. 24). These factors are fundamentally relevant to understand the mechanisms of TB infection in habitable, spaces and could be useful to profile the specific physical characteristics of high risk dwelling spaces in slums. It should be highlighted that natural ventilation and sunlight are attributes which depend mainly on the conditions and phenomena in the natural environment, i.e. weather, seasonality and geographical location. Their study, predictability and measurement are study subjects of other professional fields.

Inadequate ventilation

There are many studies linking insufficient ventilation with the increase of disease transmission (Atkinson and WHO, 2009, p. 17). Low ventilation rates prevents indoor air renewal and consequently, the dilution or removal of infectious droplet nuclei indoors (Bozzi et al., 1994). This could result in higher concentration of microbes in the air for longer periods, increasing the risk of transmission for co-inhabitants of the affected. Moreover, it has been calculated that half of the total air intake in lifetime is breathed indoors (Hobday and Dancer, 2013, p. 276). A study made by R. Wood in South Africa, linked indoor air volume exchange with high incidence rates of TB, and suggested that carbon dioxide behaves in a similar way as small particles which can transmit MTB (Forum on Microbial Threats et al., 2018, pp. 53–55).

Lack of indoor exposure to sunlight

Sunlight scarcity has been related with different mental and physical health problems in the human-made environment. Vitamin D production is influenced by the level of exposure to daylight, and its deficiency has relations with physical illnesses, i.e. bone and heart diseases, multiple sclerosis and cancer (Boubekri, 2008). Further effects of vitamin D deficiency could include undermined immunity which could lead to TB activation in susceptible communities (Ustianowski et al., 2005). On the other side, shadowed spaces could create suitable environments for the concentration of microbes, thus sunlight underexposure could preserve MTB droplet nuclei and small particles to remain airborne. The latter was suggested in two studies held in Hong Kong, where high TB rates in lower levels of high-rise buildings were related with insufficient provision of sunlight and obstruction by neighboring buildings (Lai et al., 2013; Low et al., 2013).

Relatively small enclosed spaces

Small spaces have been linked with unregulated housing development, which restricts the behavior of household members and produce negative outcomes in health (Barton et al., 2015, p. 409). The evidence suggests that MTB transmission happens in settings with limited sizes and high occupation rates (Churchyard et al., 2017; Mathema et al., 2017). It can be assumed that the risk of transmission in reduced spaces will depend on their crowding levels, thus the characteristics of this factor are linked with the exposure factor of crowding, which will be described in the section of exposure factors.

3.2.2. Exposure factors

Exposed subjects will have higher risk of TB contagion if they are close to the infection source (proximity), have contact with the affected more frequently (frequency) and through longer periods of time (duration) (Bozzi et al., 1994; CDC, 2013, p. 24). It can be supposed that these three factors would not be always involved in each MTB infection, however, some settings could promote their overlapping. For instance, prolonged and frequent close contact between people could be a common characteristic of crowded housing in slums and overpopulated prisons.

Proximity

TB and other airborne pathogens could be easily transmitted through close contact. Figure 1 shows that high airborne exposure can happen when the distance between the affected and a susceptible subject is less than 1.5 meters, and outside this range small droplets could be further dispersed with the aid of air currents (Forum on Microbial Threats et al., 2018, p. 23). Although it could be assumed that taking further distance from the source would be a preventive measure to decrease the risk of infection, there are certain settings and situations which could promote closer contact. For instance, high demand of public transport buses during high peak hours could result in bus overcrowding and close contact with affected people, therefore increasing TB transmission risk for bus riders and transportation workers (Furukawa et al., 2014). This factor has especial relevance for investigations on epidemiology of infectious diseases and urban health, because contact and concentration of people, despite its time and frequency, is a common factor of urban contexts (Barton et al., 2015).

Overcrowding in housing

In the context of urban planning, overcrowding is considered to be a phenomenon resulting from the high concentration of dwellings or people in reduced urban districts, which leads to insufficient space for the inhabitants (Davies and Jokiniemi, 2008). Worldwide, crowding conditions in housing is associated with low-income socioeconomic status (SES) (WHO et al., 2018, p. 22). Contact with air and surfaces which other people breath and touch are increased by this determinant (Moore et al., 2003, p. 272), leading to several physical illnesses, including gastroenteritis and diarrheal diseases (WHO et al., 2018, p. 25). Moreover, the vulnerability of people to volatile and droplet-transmitted infections could be augmented by crowding, through the increase of frequency, duration and mode of contact with those infectious agents (WHO, 1988, p. 23). Tuberculosis epidemics association with high levels of crowding in poor household dwellings, was firmly done by Robert Koch (Koch, 1901), and confirmed by recent studies in both developed and developing countries (Baker, Das, Venugopal, & Howden-Chapman, 2008; Tornee et al., 2005). Coincidently, crowding has been mostly related with insufficient spaces between buildings (WHO, 1988). Despite the historical focus in household transmission of TB, there is also evidence that approximately less than 19% of the cases in some countries is attributable to contagion in households (Churchyard et al., 2017; Mathema et al., 2017). This might be due to exposure in other high risk settings outside the housing units and prevalence of other diseases like HIV (Mathema et al., 2017).

On the other hand, further negative health outcomes of this factor are related with disturbances in mental health and social relations. Proximity and lack of privacy, could result in increased mental stresses, i.e. domestic violence, child abuse, low self-esteem and depression (Moore et al., 2003, p. 272; Sheuya, 2008, p. 301; WHO, 1988, p. 25). Moreover, overcrowding could affect sleep rhythms and consequently influence negatively other aspects of life, i.e. children education (Reynolds, 2005; WHO, 1988).

3.3. Preventive measures

Treatment and preventive measures against TB through the provision of natural attributes, has been a widespread belief in recent history which shaped architectural solutions and regulations to create healthier environments (Campbell, 2005). Preventive benefits of these attributes have been further understood in recent times. Actions to reduce the risk of transmission in the built environment, would logically have to tackle both environmental and exposure factors.

Provision of natural ventilation and ‘double-sided’ ventilation

This attribute is helpful to dilute airborne microorganisms and reduce their concentration by mixing uncontaminated air and removing it from the room (AAOS and ACEP, 2012, p. 39; Bozzi et al., 1994). Additionally, natural ventilation can remove pollutants or vitiated air, remove odors and “preserve an indoor climate that is dust free, at the correct temperature and humidity, and with adequate air movement conducive to health and comfort of inhabitants” (WHO, 1988, pp. 141–144). Regarding airborne diseases like TB, it has been stated that better ventilated areas present a lower risk of MTB transmission (Atkinson and WHO, 2009, p. 18). Dilution capability can be increased by high ventilation rates, thus further reducing the risk of airborne infection (Atkinson and WHO, 2009, pp. 17–18). Such effect can be fostered with 'double-sided' ventilation (WHO, 1988, p. 145). Likewise, carbon dioxide was found to be disseminated in spaces which had crossed ventilation in the study conducted by Wood, suggesting that such spaces presented a lower risk for TB transmission (Forum on Microbial Threats et al., 2018, p. 53). On the other side, single-sided ventilation may be insufficient to assure adequate indoor air changes per hour (Atkinson and WHO, 2009, pp. 27–28). Moreover, air renewal rates can be increased by 100% more in rooms with crossed ventilation than in rooms having 'single-sided' ventilation (WHO, 1988, p. 145).

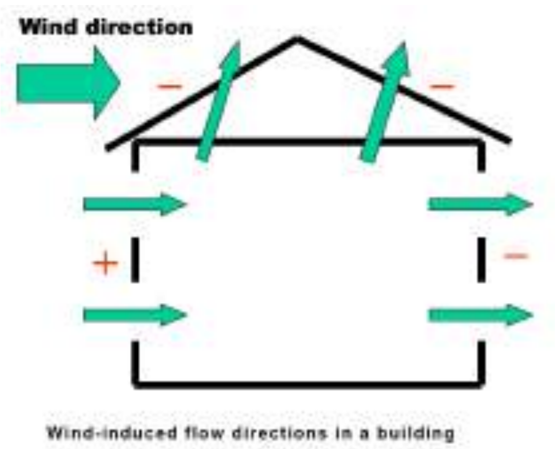

Figure 8: 'Double-sided' ventilation induced by wind flow. Source: Atkinson and WHO, 2009

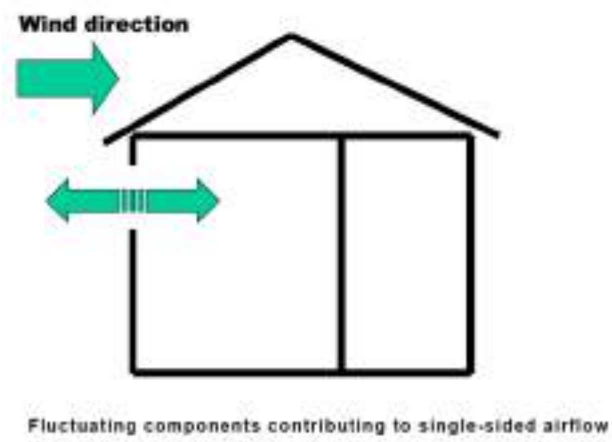

Figure 9: 'Single-sided' ventilation. Source: Atkinson and WHO, 2009.

Natural ventilation happens when outdoor air is distributed inside a room to provide healthy air for breading. Outdoor air driven by natural forces can enter indoor spaces though "purpose built openings", i.e. windows, doors, solar chimneys, wind towers and trickle ventilators (Atkinson and WHO, 2009, p. 7). Nonetheless, openings could not be always used to induce air movement, as other disadvantages may be presented, i.e. safety concerns and outdoor environmental pollutants (Hobday and Dancer, 2013, p. 275). The size of the air pressure differences inside and outside the rooms, and the size and characteristics of the openings will determine ventilation rates (WHO, 1988, p. 144). The number of openings and their location in rooms will also influence the type of ventilation effect. Thus, openings in opposite walls will create 'double-sided' or crossed ventilation, whereas 'single-sided' ventilation is be created in rooms which have openings in a single wall.

Provision of sunlight

Direct exposure to sunlight have both physiological and psychological benefits for human beings by providing thermal comfort, stimulating biological activity in the body and mental connection with the outdoors (WHO, 1988, p. 162). It can be easily assumed that daylight can improve and prevent the negative health outcomes mentioned above, by fostering the production of vitamin D, nevertheless this attribute also have effects over microbes which could be translated into further health benefits. Ultra violet radiation, which is present in sunlight, has a bactericidal effect inside buildings over many microorganism including TB (Hobday and Dancer, 2013; WHO, 1988).

In 1890, Robert Koch claimed that "direct sunlight could kill the bacillus in few minutes or several hours, through glass", whereas more recent studies imply that MTB can survive 2-3 months in the shadows (Hobday and Dancer, 2013, p. 276). Additionally, direct sunlight has been found to be more effective in killing MTB than diffuse light, which could neutralize the bacillus in 5 to 7 days (Hobday and Dancer, 2013, p. 276). Consequently, the improvement of vitamin D production by the biological effects of sunlight exposure, could have positive effects for the immune system. This could help prevent the development of active TB among people with LTBI, as suggested in a study about TB prevalence and populations with vitamin D deficiency held in London (Ustianowski et al., 2005).

Light can be brought inside spaces in buildings through openings in exterior envelopes or facades. Although windows are the most common elements used to achieve indoor natural illumination for conventional solutions, more sophisticated solutions could bring in the attribute inside enclosed spaces, i.e. 'solar pipes' (Boubekri, 2008). However, it can be assumed that windows are the optimal solution as they provide views to the outside which result in further positive perceptions, besides the features mentioned above (Boubekri, 2008).

Figure 10: Effect of the 'light pipe' in a space underground. Source: Boubekri, 2008.

Adequate space between buildings, orientation and open spaces

Sufficient spacing of buildings has been related with ensuring privacy and preventing shadowing effects between buildings, which leads to adequate provision of sunlight, air circulation around buildings and consequently ventilation of rooms. Depending on climate and weather, these attributes can be maximized by the orientation of the buildings and by open spaces, (WHO, 1988, pp. 19, 34). These factors could therefore influence positively the prevention of diseases associated with poor natural lighting and ventilation, and may be regulated by urban planning standards which can be legally enforced (WHO, 1988).

Sufficient living space

In housing, rooms with sufficient space and adequate shapes can ensure the normal performance of daily activities and social needs, i.e. cooking, eating, relaxing, sleeping and storing. Appropriate house size can allow division of activities, foster contact within the household and leave place for privacy. The influence on health outcomes has been linked with the reduction of infectious diseases transmission, mental stress, anxiety, and depression (Reynolds, 2005; WHO, 1988). Sufficient space can be achieved by an accurate design which recognizes the activities held at home, their differences on the needs for privacy, the number of household members involved and the environment desired to perform them, also considering adaptability over time because household sizes can change (Barton et al., 2015, p. 408).

3.4. Implications of applying preventive measures in slums

It is assumed that any intervention in the built environment of slums to decrease the risks of airborne infectious diseases through the provision of sunlight, ventilation and living space, would imply physical changes in the existing slum urban infrastructure and housing. Despite the methodologies to include these attributes, a discussion can be raised around the level and size of the changes needed to reach that goal, and its possible effects among slum dwellers. For instance, the WHO in its 'Guidelines for Healthy Housing' of 1988, mentions the possibility of creating open space through slum clearance, also considering a 'relaxation of measures' through 'selective demolition', depending on the conditions of the slums. It can be argued that any kind of demolition proposal, especially in long-standing slums, could influence the life and acceptability of the residents towards the project. Therefore, careful policies, planning, and design should be carried out to avoid practices which can lead to the perpetuation of negative health outcomes.

As mentioned before, in the global north radical slum clearances throughout the 19th and early 20th century where sought to improve public health, following sanitary discourses that would be later radicalized in modernist ideas. For instance, the relation of hygiene and moral health of society with the layout of cities (Campbell, 2005). This influenced the development of modernist housing projects which deteriorated over time to become slum-like places. The most iconic example was the Pruitt-Igoe housing development, which replaced a slum and ironically demolished two decades due to deterioration and increase in crime. Parallelly, Jane Jacobs pointed out the possible negative outcomes of the 'best-intentioned urban planning efforts' unless they are grounded on data (Putnam and Quinn, 2007). Recognizing the holistic understanding of Jacobs around the complexities of urban life, one can assume that these data include the study of social relations in the area to intervein.

More recently, Vanessa Watson made further critics on the negative effects of contemporary urban planning in the global south, for instance linking the prioritization of urban aesthetics or advantaged actors with bulldozing, eviction and the perpetuation of social exclusion (Watson, 2009). Relocation and eviction have been associated with negative effects on mental health and disruption of social connections among affected people, despite the possible improvement on housing (Keene and Geronimus, 2011; Thomson, 2003). A more recent example of worsening effects of planning mismatch, is the case of Natwar Parekh compound, a social housing development built in 2008 for former slum dwellers in Mumbai, which is blamed for the increase of tuberculosis rates (Chandrashekhar, 2018).

On the other side, less disruptive approaches to enhance the quality of life in slums have been tested with positive results. For instance, integrated slum upgrading has been applied in different cities around the world and linked with positive health outcomes (Corburn and Sverdlik, 2017). This holistic approach tackles issues related with housing, infrastructure, social services, livelihoods and promotes the official recognition of residents. Moreover, it is incremental model which seeks for the integration of slums to the city, involves dwellers actively in the project, and policies design and implementation, and foresees future problems related with climate change (Cities Alliance, n.d.). Although, studies of health implications of housing upgrading in different cities within this scheme, showed an increase on the sense of safety and reduction on parasitic infestations and diarrhea, there is no mention of reduced airborne infections (Corburn and Sverdlik, 2017).

3.5. Upgrading experiences in Peru

In Peru unlike other countries in Latin America, integral slum upgrading projects are rarely implemented. Although the provision of water, electrification and sanitation is commonly carried out by the government and private sector, a considerable percentage of slum dwellers in Lima have no access to this services (Calderón et al., 2015). Moreover, self-help housing is still advocated through financial and technical assistance programs, yet mostly facilitated through titling. Nevertheless, this upgrading process has been calculated to happen between twenty and thirty years starting from scratch (Calderón et al., 2015). Likewise, the measurement of housing quality upgrading done in informal settlements in Peru, focuses mainly on the structural consolidation of the houses with the use of more resistant materials and the provision of services, bypassing occupancy rates or crowding conditions. A possible explanation for the latter, is the lack of recognition of the housing issue in Peru among policy-makers and academicians (Calderón et al., 2015, p. 25).

Figure 11: The housing module built by IVUC and PIH. Source: IVUC, 2015.

Perhaps, the only milestone in housing upgrading for TB affected in Peru, was the prototype developed by joint efforts of the NGO 'Partners in Health' (PIH) and the University of 'San Martin de Porres'. The prototype was realized to aid a low-income family with TB affected members and sought to increase ventilation rates, giving sufficient space, and the use of carefully selected materials to match structural and biological security (IVUC, 2015). However, the module was considered to be expensive for low-income household affordability (Lecca, 2019). Likewise, the NGO PIH by itself carried out a program of prefabricated room modules to isolate the affected, which could be installed in existing housing structures. Post-implementation studies are lacking, therefore no concrete affirmations can be done on how these projects improved the health of the affected as assumed in their design guidelines. On the other side, public efforts to mitigate the spread of airborne disease in Lima, seem to be weak and insufficient when compared to those mentioned above. In San Cosme Hill, the 'whitewash your street' program sought to eliminate microbes and reduce mold on walls (Andina, 2011; Kapstein López and Aranda Dioses, 2014).

4. Study cases

Considering the complexity of the urban system of Lima which is composed of clearly differentiated places interconnected (Kapstein López and Aranda Dioses, 2014), and its topographical conditions composed mainly by flat land and hills, slum settlements could be classified into two broad groups: slums on hills or sloped lands, and the ones in flatlands. This classification englobes the slums which Kapstein and Aranda call 'inner peripheries', the slums located in the periphery, and those located in historical or old neighborhoods. Additionally, these settlements are usually located in high TB incidence districts with 'hot spots' in the central ones. Thus, going towards the research aim, the selection of the study areas were done following these criteria:

- High endemicity area of TB;

- The topography of the area: hill and flat land;

- Urban tissue: irregular or regular;

- Historic relevance.

The areas which comply with the criteria mentioned are: 'San Cosme Hill' and 'Barrios Altos'. Both are recognized neighborhoods in the city and are geographically located in the so-called 'Central Lima' (FIGURE). The addition of the historic relevance criteria was made to understand how the urban development in these areas determined their current physical conditions, to suggest a possible relation between gradual deterioration and TB endemicity. This could be used to foresee implications for recently settled slums in the future.

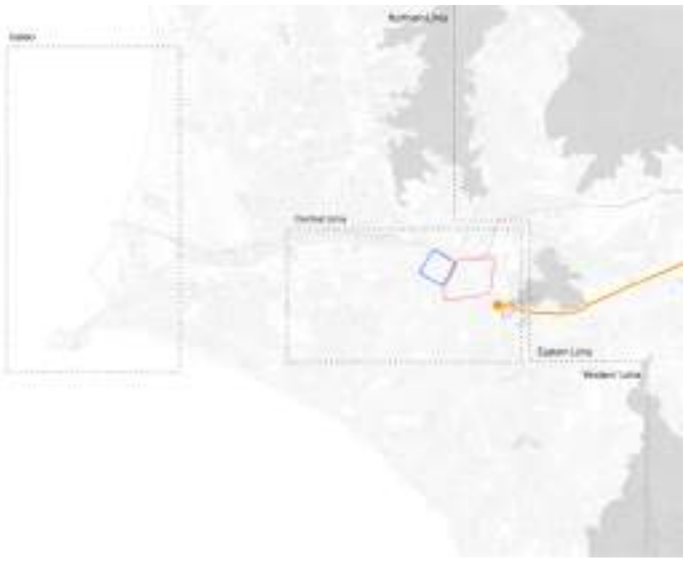

Figure 12: Map of Lima showing the study areas. Source: author.

4.1. Introduction: rural-urban migration and informal development in Lima

Lima concentrates the political power and economic opportunities of Peru as a legacy of the former Spaniard Viceroy during the colonial period (Chambers, 2005). Before 1950s, the lifestyles in the city were close to the colonial Hispanic and north American values, in contrast with the Andean indigenous culture which remained in the rural areas (Matos Mar, 1984, p. 28). The polarization was also economic, for all the attempts to de-centralize the country in previous decades were unsuccessful. However, modernization processes carried out since the 1940s resulted in the growth of the internal market and the expansion of the vial network, which enhanced the communication between the coastal cities and the rural areas. Rural-urban migration waves of people seeking for opportunities to improve their lives and running away from extreme poverty, were facilitated by the latter conditions (Sakay et al., 2011). On the other side, until 1950s the urban growth in Lima was controlled and regulated following the official parameters of Municipal urban development plans, which were rigid and not suitable for the way of life of countryside migrants (Matos Mar, 1984).

Housing alternatives were not provided at the speed of the new arrivals. This situation pushed migrants to perform the first squatting events in public and private land. Carried out since 1946 in centrally located hills and mountain foot-hills, (i.e. San Cristóbal and San Cosme Hill) or in the banks of the Rímac River, they sought to be close to economic opportunities (Chambers, 2005; Kapstein López and Aranda Dioses, 2014, p. 36). Later, further lands in the northern part of the city where squatted and the center gradually occupied, meanwhile native population moved out of the central area of Lima mainly to districts in the south, resulting in an unprecedented urban sprawl (Matos Mar, 1984; Meng and Hall, 2006). Moreover, job opportunities if available were rapidly overrun, and the rigidness of the formal labor market pushed migrants to informal economic activities as an alternative (Matos Mar, 1984). That phenomenon defined the profile of the urban economy in Peru until today.

Between the 60s and the 70s, the city extended to the south and during the 70s towards the central Andes (Kapstein López and Aranda Dioses, 2014). By the time, the government had already embraced the self-help approach to allow and sometimes assist migrants in the creation of their neighborhoods from scratch. Once settled and titles given, the government would proceed to the implementation of services. In this context, the squatters organization into neighbors associations were essential for their empowering and mobilization, which allow them to put pressure on the authorities to negotiate the allocation of their rights (Calderón et al., 2015). One of the most representative settlements of this period is 'Villa El Salvador', located in an arid coastal land and self-built from scratch, which is currently well consolidated and integrated to the city.

Picture 1: Squatting process and consolidation of Villa el Salvador. Source: (El Universo, 2018).

In the 80s and 90s, migration waves were mostly triggered by two events: ‘El Niño’ effect, which left thousands of people homeless along northern coastal cities and towns, and the internal conflict between the government and terrorist groups, which exposed rural populations to continuous violence: Lima received in this period 351,670 internal refugees from different areas with terrorist influence (Chambers, 2005). By 1981, 40% of the population in Lima had migrant background, most of them from the central Andean region, which gradually changed the social dynamics of the city with cultural expressions from the countryside (Matos Mar, 1984). Large migration waves in Lima remain happening between the 90s and early 2000s, sometimes widely fostered by political clientelism (Calderón et al., 2015). Throughout this process, the population in Lima grew from 661,508 in 1940 to 9,9904,727 in 2015 and it is projected to reach 13,083,114 by 2035 (ANA and Observatorio del Agua, n.d.).

Figure 13: Population growth in the Metropolitan Area of Lima from 1940 to 2035. Source: ANA & Observatorio del Agua.

4.1.1. Current approaches and challenges

The self-help approach was legitimized as an adequate response to alleviate the housing shortage, worsen by the rapid increase of urbanization, poverty and political instability (Dupont, 2016; Kapstein López and Aranda Dioses, 2014). Under these scheme, living conditions have been improved in some of the oldest squatting settlements through an incremental process carried out by the households themselves, with or without the assistance of the government (Calderón et al., 2015; Sakay et al., 2011). These areas have been almost completely integrated to the city and services have been provided, however some of they still preserve social issues inherited since the time they were slums (i.e. crime and poorly developed infrastructure) (Kapstein López and Aranda Dioses, 2014). Likewise, a certain disparity on the development speed can be noted among different areas originated through squatting (Calderón et al., 2015). This might be due to differences in contributive factors such as individual and community priorities, government policies, household motivation, health status, community spirit and financial resources (Chambers, 2005). The other side of the coin is the proliferation of informal real estate agents or ‘land traffickers’ which organize land occupations to sell in the informal market (Dupont, 2016). Moreover, the self-help scheme and services provision was until recent times abused for clientelist strategies of politicians, making the existence of slums convenient (Calderón et al., 2015).

Picture 2: View of 'Ciudad de Gosen', squatting settlement started more than 20 years ago. Source: the author.

Despite that self-help policy helped relief the Peruvian government from housing demand backlogs, its social housing projects are small scale and hardly supply the poorest from affordable alternatives, notwithstanding the flexibility of financing and credit programs (Calderón et al., 2015; Meng and Hall, 2006). Furthermore, there seems to be a recent switch in the official narratives concerning the urban development of Lima, probably triggered by the recent economic stability, which seeks to prioritize private investment on the development of the city (Dupont, 2016). This might gradually replace the self-help approach and summon speculators to attractive land especially in central areas, where some slum settlements remain. However, the self-help policy is still applied, new squatting settlements appear, and Lima continues its urban sprawl. In this scenario, future challenges will continue to emerge and the capacity of the government (and the private sector) to address them will be again questioned. In the last years, Peru has received migration waves of more than 750'000 Venezuelan refugees seeking for economic opportunities and shelter in the cities, meanwhile settlements remaining as slums wait to finally even their development with the rest of the city.

4.2. Case study 1: Cerro San Cosme

The slum “Cerro San Cosme” (CSC) is located in the Lima, specifically in the central area known as ‘Central Lima’. It is widely connected with access to the national-level economic hub of ‘Gamarra’, the central Andean part of the country through the Central Highway, and to the middle and upper-class districts of ‘Modern Lima’ with access to a metro line. Likewise, ‘El Agustino Hill’ and ‘El Pino Hill’, are slums located nearby which share a common history and similar issues with CSC. Founded in 1946, it is one of the oldest informal settlements started from scratch by migrants who came from the inner provinces of the country. The new mixed cultural identity resulting from the clash of the urban and rural lifestyles had in this place its highest expressions, which mainstreams its popularity among citizens with a migrant background. Despite the positive associations with a culture of hard-working rural-urban migrants, CSC carries a heavy burden of social problems which affects negatively its external image.

Figure 14: Map of San Cosme, connectivity and surroundings. Source: Author.

The area is depicted by mainstream media as a nest for crime, drug dealing, substance abuse, informality, unsanitary conditions, and tuberculosis. Some residents have shown their disconformity with these narratives and even deny the prevalence of TB, particularly inside the hill. At this point, it should be highlighted that TB incidence in CSC is five times bigger than the national rates (Fuentes-Tafur, 2009, p. 377). The accurate geographic location of the cases is yet to be analyzed, as there is a debate among the residents on where most of these are; inside or at the surroundings of the hill, however, the fact that it is a 'hot spot' for TB is undeniable. Although the origin of this epidemic has not been properly inquired yet, the first cases of TB are known to have happened within the first years of the squatting settlement.

Picture 3: San Cosme Hill from the Metro Station. Source: the author.

4.2.1. Urban development of CSC.

Since the construction of the market known as 'La Parada' was made next to San Cosme Hill in the year 1946, which attracted newcomers interested in the trade of agricultural products throughout decades. Rural migrants were the first to arrive and settle in the proximities of the commercial hub, starting the squatter mobilization which resulted in the creation of the Neighbors Association of CSC (Kapstein López and Aranda Dioses, 2014, p. 49). Changes in the political sphere and concrete political actors legitimized the process of land squatting, which supported this specific case (Matos Mar, 1977).

The convenient location of the hill was determinant for its over-densification. By 2007, the National Statistics and Informatics Institute of Peru (INEI, 2008), reported that CSC hosted almost 20,000 inhabitants with a density of 2054 p/ha, one of the highest in the metropolitan region of Lima (PLAM 2035, 2014). Despite the improvements of infrastructure and the implementation of services carried out during the 90s, CSC can be considered as a slum according to the characteristics framed by the UN-Habitat (UN-Habitat, 2003). The most evident deficiencies of CSC up to date are the lack of sufficient living space and low-quality housing. Moreover, it could be said that access to clean water, adequate sanitation, or secure tenure, are not adequately provided to all the residents.

Picture 4: San Cosme in its first years. Source: National Aero-photography Service

During the process of squatting consolidation, rudimentary shacks were turning into houses with the use of stronger construction materials. Dwellings units were built encrusted into the hill taking positions which followed its topography. On the other side, the economic vibrancy of the area could have enhanced contestation over the space to establish businesses and housing, which might have driven further divisions and sub-divisions of plots. San Cosme hill has approximately 150 meters height, which could be considered low compared to others in Lima where informal settlements have appeared. Residents expressed their proud and are confident in the structures built by their parents, which resisted several earthquakes through history. However, those expressions can be questioned considering the informal nature of the constructions, the lack of technical supervision and continuous forecasts of stronger seismic events in the nearest future.

In 2012, ‘La Parada’ market’, one of the most important economic hubs of Lima yet a place of insecurity and sanitary issues, was forcibly closed by municipal authorities which alleged a ‘sanitary emergency’. The implications of the forced eviction on the ambulant vendors, traders, and their families have not been studied. In 2014, the ‘Park of the Migrant’ (Green in Figure 8), was built on the place of the market, to provide open space and leisure activities. It is still unknown if this new infrastructure had in any way influenced the quality of life among residents in CSC and nearby areas, though its study would clarify the outcomes of such processes. This 2019, the new mayor of the district announced his intentions to build a commercial building underground the park, raising new discussions and critics around market-driven policies and projects, meanwhile further social issues including TB are still rampant in CSC and other locations nearby.

Picture 5: Aerial view of the 'Park of the Migrant'. Source: SERPAR

4.3. Case study 2: Barrios Altos

This neighborhood is located in a slightly elevated area compared with old town of the city, which gave origin to its name: “high neighborhoods”. Placed in ‘Central Lima’, Barrios Altos (BA) is conveniently connected to the rest of the city through wide avenues and access to the metro line. It was initially occupied by poor Spaniards, independent indigenous people and former slaves during colonial times. Nevertheless, its location at the near periphery of the colonial city, made it the preferred place of residence for any visitors and merchants which decided to stay in the city (Reyes Flores, 2004). Later in the republican era, Italian, Chinese, Japanese migrants and some families of the local economic elite chose the area to live permanently (Reyes Flores, 2005, p. 225). Many relevant Peruvian personalities of arts, politics and science also dwelled in the neighborhood, which coincidently is recognized for the vibrancy of its community life. The settings for neighbor activities were the ‘callejones’, a traditional collective housing typology which is related with the old ways of urban life in Lima.

Figure 15: Map of BA showing protected areas and connectivity. Source: the author.

Since the beginning of the 20th century, cases of tuberculosis have been reported in BA, and despite the severity of the disease, romantic associations were made through local cultural expressions (Pamo-Reyna, 2014). Later, during the second half of the 20th century, this area continuously received migrants from the rural areas, which sought a convenient location nearby the old town. Today, the neighborhood partially preserves the identity of its golden times, through long standing residential, public buildings, and squares of colonial times and the early republic. However, some of the buildings are gradually being replaced by warehouses and storages sometimes secretly built behind historic facades, despite being protected and listed, for instance, as UNESCO world heritage (See figure 9). Most of the “callejones” are in bad conditions and some are in risk of collapse, though still inhabited by low-income individuals and families. On the other side, the high incidence of TB is still a burden for the residents of BA almost a century after the first reports, despite the development of biomedical solutions.

Figure 16: A street in Barrios Altos. Source: Anna Monusova, 2008.

4.3.1. Urban development of Barrios Altos

The land development of BA started in pre-Hispanic times, through the trace and construction of aqueducts for irrigation and pathways. After the foundation of the city in the 16th century, BA began to have three developments which defined its current urban tissue. The first one (I) is the short extension of the colonial ‘chess’ shaped tissue of the old town on its western side, one of the first urban expansions of the Spaniard city. Secondly, the creation of the segregated neighborhood for the indigenous people in the eastern part (III), which was determined by the pre-Hispanic pathways and the old colonial city wall, producing “long and narrow blocks”. Thirdly, the plot division for agricultural activities in the central part also influenced by pre-Hispanic aqueducts, which were the property of religious orders (Shimabukuro, 2015, p. 10). As a result of the latter, BA has an “irregular and unproportioned urban tissue” (Shimabukuro, 2015). This heterogeneity influenced human settlement typologies, which consequently could have influenced the creation of different types of buildings and ways to occupy the space. On the other side, differences on elevation are low and might had very little influence on the urban form.

The most popular housing solution since colonial times was the ‘callejones’ or alleys, a typology composed from ten to more than one hundred dwelling units with one, two or three bedrooms of 25 to 35 sqm along one or more narrow hallways and patios. ‘Callejones’ were usually built without toilets inside the dwellings; this condition persisted until the 20th century (Reyes Flores, 2004). Other traditional housing compounds are 'Quintas' and 'solares', which tend to have wider dimensions than callejones, are usually mistaken for each other.

Figure 17: Three developments which shaped BA. Source: the author, based on Shimabukuro, 2015.

BA had a vibrant economy because it was a melting pot of ethnic and socioeconomic groups. More population was attracted to the area, resulting in the highest density of inhabitants in the country by the first decades of the 20th century (Reyes Flores, 2005, p. 226). By this time, the city authorities opened new streets and demolished some 'callejones' considered to be 'infectious spots' (Reyes Flores, 2005). Housing buildings had between three and one floors, giving the neighborhood a relative uniformity similar to the one of the old colonial town. This urban environment was preserved relatively untouched until the second half of the 20th century, when the wider process of urban-rural migration started. By the 1980s, upper and middle-income families were moving out from BA to new urban developments and existing resorts in the south since the first half of the 20th century, progressively accompanied by companies and governmental institutions (Matos Mar, 1984; Meng and Hall, 2006).

Figure 18: 'Callejón' in Barrios Altos. Source: the author.

Parallelly, middle-class and low-income families occupied already deteriorated buildings left behind by better-positioned predecessors (Meng and Hall, 2006). The conditions in former elegant buildings sometimes worsened beyond recovery, most probably because of the over occupation of dwellings and the overloading of the existing services. Despite the conditions, housing buildings including 'callejones' are still used by low-income families, which exposes them to multiple health hazards. Moreover, informal entrepreneurs placed storages and warehouses to supply other business in the proximities of the old town, modifying and sometimes destroying the architectural heritage of the early republican era.

5. Field research

In chapter three, it was explained that external factors could influence the provision of sunlight, natural ventilation, and also levels of crowding in slum housing. Therefore, the field research visit started from surveying the affected dwellings through observation and measurement of their spatial characteristics, including conditions of their immediate contexts. The data obtained was later organized into three scales: neighborhood, collective housing building, and housing unit. Spatial distribution of the dwellings were sketched into layouts which depict the elements related with transmission factors, and photographs were taken with authorization of a household member. Each dwelling was later coded and organized into information sheets to be used during the analysis.

The field research visit (FRV) original aim was to survey twenty houses of TB affected people per each neighborhood. Conditions were favorable to achieve the aim only in the case of BA, whereas in CSC, many affected rejected the visits because they were busy at the moment or because of stigmatization. Therefore, eleven houses were successfully surveyed in CSC and twenty in BA. The only requirement was that at least one household member in the house is affected by TB (including MDR TB XDR TB) or was cured recently. Visits to the health centers and contact with the chief medics of the control strategy were done for both areas, to facilitate approaching the affected. Finally, a brief revision to the recent plans was done to corroborate official intentions and awareness of the epidemic.

The focus on slum housing is because it seems to be invisible for some, and the government (and involved actors) seems to be ineffective in addressing the problem of social housing. (Calderón et al., 2015; Dupont, 2016; Meng and Hall, 2006).

5.1. Exploring the role of the built environment on influencing MTB prevalence

The explanation of the factors for transmission in chapter three, depicted the characteristics of high transmission settings, whereas the section about preventive measures intended to show the benefits for health of the attributes and how to achieve them. The latter were used to build a set of specific spatial determinants to analyze the data gathered in the FRV.

It should be highlighted that the Peruvian Building Regulations generally indicates that housing are healthy environments when they are provided of natural ventilation, illumination, and sufficient living space. The requirements seem to be abstract and widely open for free interpretation, for none parameter specification around windows or occupation rates is given. Also, the orientation of buildings are not considered because their analysis would imply external factors including weather and seasonality, which could require of computational modeling.

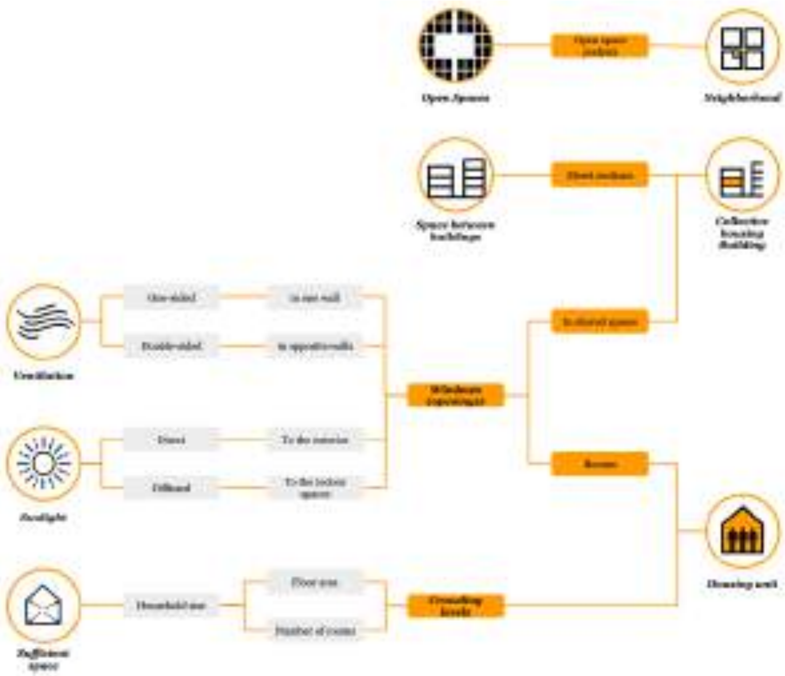

Figure 19: Construction of evaluation indicators for analysis. Source: the author.

Crowding levels: This indicator will be used to measure the availability of space and the proximity factor in dwelling units. The three elements quantified were: household size, number of (habitable) rooms, and total floor area of the dwelling, which will be used to compare with the selected crowding indexes: UN-Habitat and Argentinian National Institute of Statistics and Censuses (ANISC). Both consider that overcrowding or 'critical overcrowding' happens if there are more than three people per habitable room (WHO et al., 2018).

Openings and 'double-sided' ventilation: After the revision of chapter 3, it can be said that openings availability in indoor spaces is an indicator of the suitability for human habitability and wellbeing. The WHO has recommended the provision of at least one window per habitable room in dwelling units including circulation spaces and WCs, to ensure the provision of sunlight and natural ventilation and promote health (WHO, 1988). Additionally, the WHO recommends 'double-sided' over 'single-sided' ventilation to ensure continuous air renewal. This effect can be possible when having two windows or openings in opposite locations. Therefore, quantification and location of openings in the dwellings layouts was done for the analysis.

Openings in shared spaces: In the FRV was noted that almost all the affected lived in collective housing buildings in both neighborhoods, and shared spaces including circulation areas and toilets, which were roofed and unroofed. It was also noted that roofed shared spaces (RSS) were mostly dark and narrowed, meaning that they would present a risk of infection for other residents using them. Therefore, the provision of openings in this spaces will be measured to discuss the possibilities of natural ventilation and sunlight.

Space between buildings: Similar to the possible influence of open urban spaces, building heights and the separation distance between them are variables which create shadowing effects to block sunlight and air flows to indoor spaces (WHO, 1988, p. 19). This indicator will be measured in street sections, through street widths and building heights.

Open spaces and pockets: as explained among preventive measures in chapter 3, open spaces can enhance the provision of natural ventilation and light to surrounding buildings in a neighborhood, which could have an impact on the health of residents (WHO, 1988, p. 34). The provision of open spaces inside the urban tissue will be analyzed by comparing built and unbuilt surfaces in maps of the neighborhoods. Streets, alleys, and squares will be understood as open spaces, for they also can play a similar role.

Influence of topography: this factor is added to explore how can topography influence the ventilation and sunlight provision in buildings.

5.2. Case Study 1: Cerro San Cosme

5.2.1. Neighborhood scale

Influence of the topography

Buildings placed on the hill have different heights proportional to their floor quantities and ascending elevations. Therefore, it could be assumed that upper facades of the buildings have continuous exposure to wind flows and sunlight. Moreover, a possible Venturi effect would elevate wind speed on the top and distribute evenly on the upper parts of the buildings in the opposite direction of the wind (See Figure 20) (Al Katsaprakakis and Christakis, 2012, p. 175). The parts of buildings facing directly the facades of their front neighbors in a lower elevation, face also streets, staircases and alleys, which narrow sections could compromise negatively the natural ventilation and the period of exposure to sunlight. Consequently, it could be assumed that higher parts which have unrestricted façade exposure, when having sufficient openings, would have indoor spaces less suitable for MTB droplets and less TB cases (Lai et al., 2013).

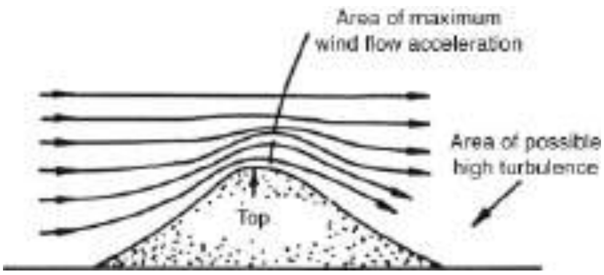

Figure 20: Venturi effect on hills. Source: Al Katsaprakakis and Christakis, 2012.

Further study and accurate computational modelling of these urban settings would allow deep analysis of the different phenomena regarding wind flow and sunlight exposure. Likewise, the linkage with the geographical and elevation mapping of TB cases would concretely depict how the build environment and the topography of slums, like the case of CSC, are creating suitable environments for MTB transmission.

Open spaces and pockets

CSC could be considered an urban island, because of its irregular morphological characteristics which differentiate it from its surroundings and make evident its spatial boundaries (Kapstein López and Aranda Dioses, 2014). Nevertheless, the spatial quality of the place could be considered as diverse with different visual experiences and interesting viewpoints in the higher parts. However, both phenomena of topographical adaptation and land contestation could have contribute to the irregular blocks and reduced spaces to be used as streets, alleys, stairs and recreational facilities, which in some cases barely allow mobility of residents by foot inside the neighborhood. Likewise, there are almost no public green areas inside CSC being only found in its immediate surroundings.

Figure 21: Alley in CSC. Source: Estephanie Quispe.

Figure 22: recreational use of the alleys and stairs. Source: Kapstein López and Aranda Dioses, 2014.

Figure 23: Concrete field for sports and children. Source: Kapstein López and Aranda Dioses, 2014.

Figure 24: Map of CSC showing the approximate built and unbuilt area. Source: the author.

The plan shows the proportion of approximate built surfaces (black) inside the neighborhood, outside (gray), and unbuilt surfaces (white), which allows to have clear perspective of urban open space availability. Open spaces inside the study area seem to be scarce. Besides avenues, streets, alleys and stairs, the only spaces with considerable dimensions are outside the hill: a primary school and sports center, and the Park of The Migrant to the left. Moreover, inside the hill several small open space pockets with irregular shapes are noted, which are located mostly nearby alley intersections. The most visible one is in the central part of the hill where a concrete field is located in the highest point. Nevertheless, alleys and narrow streets outlining the topographic boundaries of CSC, seem to be the most common feature of the urban tissue, reflecting tight distances between buildings.

5.2.2. Collective housing scale

Openings in Shared spaces

The most common roofed shared space (RSS) of circulation among the studied buildings in CSC are corridors, as shown in table 1. Although table 2 shows that out of those 7 only 1 had an opening to the outside. Likewise, the affected share at least one toilet or bathrooms with their neighbors in 7 cases, from which only 2 had openings to the outside, making these spaces possible good environments for MTB droplets. Additionally, it can be thought that shared toilets or bathrooms could be used for longer periods than corridors, meaning that neighbors could be exposed for a longer time to the pathogen increasing probabilities for infection. Nevertheless, corridors with no openings would expose more neighbors to MTB droplets.

Table 1: Roofed shared spaces between the affected and their neighbors inside the collective housing unit or compound

Case study code	Shared Roofed spaces					Total
	Toilet or bathroom	Vestibule	Stairs	Hallway	Corridors	
CSC.V1.01	1	1	1	0	1	4
CSC.V1.02	1	0	0	0	0	1
CSC.V2.01	1	0	1	0	1	3
CSC.V3.01	1	0	0	0	0	1
CSC.V3.02	0	1	1	1	1	4
CSC.V4.01	0	0	0	0	0	0
CSC.V5.01	0	0	0	0	1	1
CSC.V5.02	1	0	0	0	1	2
CSC.V5.03	1	0	1	1	1	4
CSC.V6.01	0	0	0	0	1	1
CSC.V7.01	1	0	0	0	0	1
	7	2	4	2	7	22

Table 2: Shared spaces between the affected and their neighbors inside the building or housing compound: quantity of windows, skylights or openings to the outside in roofed spaces (not including doors)

Case study code	Shared Roofed Spaces					Total
	Toilet or bathroom	Vestibule	Stairs	Hallways	Corridors	
CSC.V1.01	0	1	0		0	1
CSC.V1.02	0					0
CSC.V2.01	0		0		0	0
CSC.V3.01	0					0
CSC.V3.02	1	1				2
CSC.V4.01						
CSC.V5.01					0	0
CSC.V5.02	0				1	1
CSC.V5.03	1		0	0	0	1
CSC.V6.01					0	0
CSC.V7.01	0					0

Figure 25: Shared unroofed hallway in squatted roof of market. Source: the author.

Figure 26: Shared roofed access corridor in horizontal housing building. Source: the author.

Space between buildings

To show the proportional relations, the analysis is performed using sections through the affected dwelling units, to display their immediate surroundings and depict any spatial characteristics which might be adequate environments for infection.

Table 3: Heights and distance between buildings

Case study code	Number of floors of building studied	Number of floors of front neighbor	Distance between structures (meters)	External circulation space typology	Circulation space inside compound
CSC.V1.01	4	4	1.5	Alley	
CSC.V1.02	3	1	1		Unroofed hallway
CSC.V2.01	3	1	10	Avenue	
CSC.V3.01	3	2	1		Unroofed hallway balcony
CSC.V3.02	4	4	18	Street	
CSC.V4.01	2	2	1.5	Alley	
CSC.V5.01	2	2	1.7		Unroofed hallway
CSC.V5.02	2	3	18	Avenue	Unroofed hallway
CSC.V5.03	2	3	3.1	Alley	
CSC.V6.01	1	1	6		Unroofed vestibule
CSC.V7.01	4	2	1	Alley	

The structures with the tightest proportions (CSC.V1.01, CSC.V4.01 and CSC.V7.01), are facing alleys between 1.5 and 1 meters wide, in relation with 2 to 4 floor height buildings (approximately 6 to 8 meters height). These are located into the organic urban tissue of the hill. Hence, their conditions might heavily limit indoor spaces and dwelling units inside to benefit from sunlight and wind flows.

Figure 28: Collective housing buildings separated by alleys. Source: the author.

Figure 27: Alley and stairs inside CSC. Source: the author.

Figure 29: View to the alley from surveyed house. Source: the author.

5.2.3. Housing unit scale

During the first years of the settlement on CSC, housing structures were built using earthen bricks and other rudimentary materials, although most of them were later consolidated using clay bricks, concrete and steel. Moreover, some of the oldest residents in CSC have claimed their parents "carved the hill" to build their houses, still persisting despite several tremors and earthquakes throughout time. Notwithstanding the relative new condition of structural stability, houses were built in small irregularly shaped plots or encroached inside other subdivided plots. This resulted on enclosed indoor living spaces, which in some cases have overly reduced exposure to the outdoors when occupying unsuitable spaces to dwell. An example of this are the so-called 'mole houses', which are basements serving as dwelling spaces.

During the FRV, three typologies of dwellings were noted: bedrooms, studios and apartments. The most common ones, bedrooms and studios had one to two rooms respectively, and apartments had from three to five rooms. The first were part of bigger properties of multistory buildings in small plots or backyard extensions in longer plots.

Crowding levels

Dwelling units of the affected which were visited in CSC can be classified into three typologies: bedrooms, studios and apartments. The latter could be considered the biggest dwellings with 4 to 7 rooms, meanwhile studios and bedrooms only presented 2 to 1 rooms respectively. Despite the quantity of rooms, these cases could still be considered as tight living spaces when comparing the available area with the number of household members using it. Table 4 shows all the cases with their respective floor areas per person. The highest rates are found in apartments between 2 and 5 sqm per person. Also, bedrooms have the lowest rates, hosting as much as 6 persons in only 12 sqm (See layout of case CSC.V3.01).

Table 4: Floor area per person among the cases analyzed in CSC

Case study code	Building typology of the study case	Type of dwelling unit	Approximate area	Floor area per person	Number of dwellers
CSC.V1.01	VS	Bedroom	9	2,3	4
CSC.V1.02	HS	Apartment	38	7,6	5
CSC.V2.01	VS	Bedroom	15	3,8	4
CSC.V3.01	HS	Bedroom	12	2,0	6
CSC.V3.02	VS	Bedroom	10,5	10,5	1
CSC.V4.01	VS	Apartment	25	2,5	10
CSC.V5.01	HS	Apartment	44,7	14,9	3
CSC.V5.02	HS	Studio	22,6	7,5	3
CSC.V5.03	HS	Studio	18,6	9,3	2
CSC.V6.01	HS	Apartment	49	7,0	7
CSC.V7.01	VS	Studio	20	5,0	4

Crowding levels are clearer when comparing the number of inhabitants with the number of rooms considered ‘habitable’ by the indexes selected. As seen in table 5, five out of the eleven dwellings are considered to be crowded or critically crowded by the two indexes selected (UN-Habitat and ANISC). These dwellings have an average of more than 4 inhabitants per room.

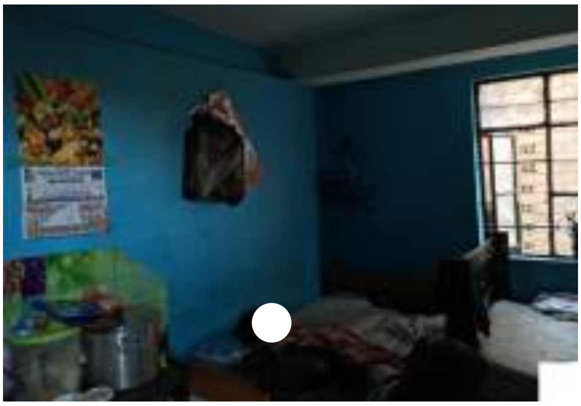

Figure 31: Interior of bedroom occupied by a household. Source: the author.

Figure 30: interior of two room studio. Source: the author.

Table 5: Measuring crowding in the dwelling units

Case study code	Type of dwelling unit	Total Number of rooms	Number of habitable rooms	Number of dwellers	Dweller per room	Measures of Crowding	
						UN-Habitat	Argentinian National Institute of Statistics and Censuses
CSC.V1.01	Bedroom	1	1	4	4,0	Crowded	Critical Overcrowding
CSC.V1.02	Apartment	4	2	5	2,5	No	No
CSC.V2.01	Bedroom	1	1	4	4,0	Crowded	Critical Overcrowding
CSC.V3.01	Bedroom	1	1	6	6,0	Crowded	Critical Overcrowding
CSC.V3.02	Bedroom	1	1	1	1,0	No	No
CSC.V4.01	Apartment	5	3	10	3,3	Crowded	Critical Overcrowding
CSC.V5.01	Apartment	5	1	3	3,0	No	No
CSC.V5.02	Studio	2	1	3	3,0	No	No
CSC.V5.03	Studio	2	1	2	2,0	No	No
CSC.V6.01	Apartment	7	3	7	2,3	No	No
CSC.V7.01	Studio	2	1	4	4,0	Crowded	Critical Overcrowding

It could be said that under the latter crowding conditions, there is a high probability that all members in the surveyed households living in the same house are infected with MTB. Nevertheless, only two of the interviewees claimed having at least two close relatives which had the disease in the past and other six mentioned other possible settings, for instance, jails and dwellings in other cities.

Openings and 'double-sided' ventilation

Rooms in the analyzed housing units in CSC present different opening typologies and conditions which allow or foster natural ventilation and indoor air renewal: windows, holes and skylights. Meanwhile windows are defined by having closing panels and frames, almost all the holes and skylights presented no additional structure to control airflow and sunlight exposure. Despite the fact that the latter characteristic could be justified by the informal construction of the dwelling and the lack of technical supervision, it could also be taken as a positive asset when thinking about airborne infectious diseases prevention. Nevertheless it is important to understand how the provision of openings could create conditions for high-risk transmission settings.

Table 6: Number of windows or other openings (excluding doors) per habitable room and cross ventilation possibilities among dwelling units

Case study code	Type of dwelling unit	Number of bedrooms	Bedrooms with at least one openable window	Number of openable windows in social space	Cross ventilation possibilities of the layout
CSC.V1.01	Bedroom	1	1	-	Yes, when entrance door is opened through adjacent space
CSC.V1.02	Apartment	2	2	3	Yes, through windows, skylight and opening bedroom doors
CSC.V2.01	Bedroom	1	1	-	Yes, when entrance door is open through adjacent space
CSC.V3.01	Bedroom	1	1	-	Yes, through hole in opposite wall
CSC.V3.02	Bedroom	1	1	-	No
CSC.V4.01	Apartment	3	0	0	Yes, through skylights when entrance door is open
CSC.V5.01	Apartment	1	0	1	Yes but limited. Only when entrance door is open
CSC.V5.02	Studio	1	1	1	Yes but limited. Holes are in adjacent spaces and opposite directions
CSC.V5.03	Studio	1	1	-	Very limited through shared roofed hallway, if entrance door is open
CSC.V6.01	Apartment	3	1	1	Yes, through high window in corridor
CSC.V7.01	Studio	1	0	1	No

Table 6 shows the availability of windows per bedroom and social space, dismissing blocked or permanently closed windows. Among the dwelling units visited, seven out of the eleven had one window per bedroom, whereas one had three bedrooms with only one window, and three others had no windows in their bedrooms. Out of the latter, three where apartments which despite having more rooms, presented less windows per habitable spaces. Studios and bedrooms generally met the single window parameter, nevertheless, this feature could be considered insufficient or irrelevant when looking at their number of inhabitants and critical crowding conditions. On the other side, crossed ventilation possibilities are assured with sufficient openings placed in opposite locations only in three out of the eleven dwelling unit layouts analyzed. Four dwellings could create crossed ventilation by opening entrance doors, nevertheless this could eventually compromise privacy or security, being less likely to happen. Also, five dwelling units presented none or very limited conditions for cross ventilation, hence very few or no opportunities to renew indoor air.

5.2.4. PLAM 2035: urban upgrading proposal for CSC

The Metropolitan Urban Development Plan for 2035, was developed by the Municipality of Lima with assistance of UN-Habitat from 2010 to 2014 (UN-Habitat, 2015). This document had a set of prioritized programs which included the Urban Upgrading Program of San Cosme Hill, which specified actions to improve the built environment of the area. Among the problems recognized in the study of the project, are the high density of population and the incidence of tuberculosis (PLAM 2035, 2014). It should be highlighted in this plan, the recognition of health related determinants to be tackle through urban upgrading. The most remarkable idea was to 'free' area in the hill to make a ring of open space including greenery, improve connectivity and allow evacuation and emergency vehicles to reach the central area if needed. Demolition of houses and relocation of households have been contemplated in the plan, and a reasonably nearby location has been suggested to place new housing units.

Figure 32: Upgrading project for CSC. Source: PLAM 2035.

After 2014, the newly elected government in Lima by-passed the plan, and reduced its relevance to the point that its existence was denied. Possible explanations could be beyond political rivalry, probably to the prioritization of clientelist projects. Nevertheless, time has been lost for the PLAM 2035 to be implemented as it was, for the constant change the city undergoes requires update.

5.3. Case Study 2: Barrios Altos

5.3.1. Neighborhood scale

Influence of the topography

As explained above, topography of BA could have little or no impact in the development of the urban form because of its slight elevation differences. Moreover, building heights observed during the FRV remain relatively homogenous across the neighborhood and the spaces between them are sufficiently wide to host both vehicular and pedestrian flows. External facades would have no considerable obstacles against continuous and homogenous exposure to wind flows and sunlight. Nonetheless, it is relevant to study internal facades of ‘callejones’.

Open space and pockets

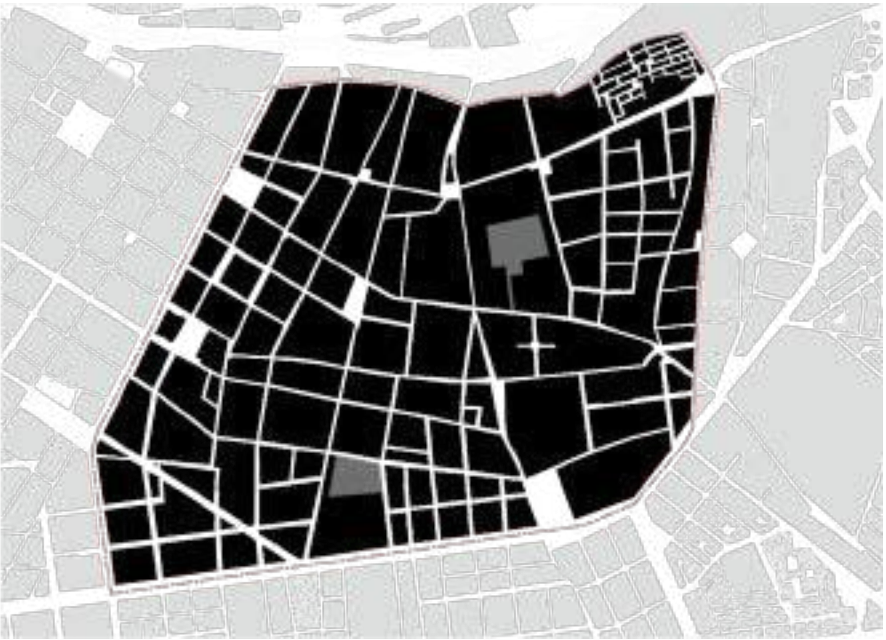

Figure 33: Map of BA showing the approximate built and unbuilt area. Source: the author.

As a result of the processes and constrains described earlier, blocks are polygons with different number of sides, dimensions and areas which vary between 2 and 11 hectares (Shimabukuro, 2015, p. 10). Nevertheless, in Figure 33 it is notable the difference between block sizes in neighboring areas and in BA. Moreover, interior ventilation and illumination inside blocks are given by particular architectonical solutions of each building typology, rather than responding to urban planning parameters.

Consequently, the surface left for open spaces (dark grey and white) seems to be unproportioned in relation with the built area (balck). Only four blocks were left empty to place parks and plazas and another five spaces are small plazas left as atriums for religious or civic buildings. Thus, it seems that open spaces are scarce in BA, which value to enhance ventilation and sunlight is essential for buildings facing them, although insufficient compared with the larger extent of the neighborhood.

5.3.2. Collective housing scale

Dwelling units in traditional typologies including 'callejones' were often designed with an interior unroofed patio, hallways, or provided with skylights. Probably, these spaces together fostered the creation of wind flows across the dwelling layout and allowed greater indoor illumination. In chapter 4, it was described that dwellings in callejones had as much as three rooms, probably to host singles, couples or small families. Nevertheless, the increase on housing demand and the extension of household members through time also constrained by the lack of housing opportunities, pushed families to gain habitable surfaces inside the existing units. These inner extensions in the houses surveyed presented mezzanines, second floors and sometimes new rooms in unroofed spaces, which allows further densification.

Openings in shared spaces

Among the housing buildings analyzed it was common to find horizontal collective housing units as described above. Every case presented an unroofed hallway, a traditional feature of the 'callejón' typology as described above which could be considered a beneficial asset. Nevertheless other factors could limit these shared spaces to benefit from natural ventilation and light, for instance the distance between neighboring structures.

Table 7: Roofed shared spaces between the affected and their neighbors inside the collective housing unit or compound

Case study code	**Roofed Shared Spaces**					**Total**
	Toilet or bathroom	**Vestibule**	**Stairs**	**Hallway**	**Corridors**	
BA.V1.01	1	0	0	1	1	3
BA.V1.02	1	0	0	0	1	2
BA.V1.03	1	0	0	0	1	2
BA.V2.01	0	0	0	0	0	0
BA.V2.02	0	0	0	0	0	0
BA.V2.03	0	0	0	0	0	0
BA.V2.04	0	1	0	0	0	1
BA.V2.05	1	0	0	0	1	2
BA.V2.06	0	1	0	0	0	1
BA.V3.01	0	0	0	0	1	1
BA.V3.02	0	0	0	0	1	1
BA.V3.03	0	0	0	0	1	1
BA.V3.04	0	0	0	0	1	1
BA.V4.01	1	0	0	0	1	2
BA.V4.02	0	0	0	0	0	0
BA.V4.03	0	0	0	0	0	0
BA.V4.04	0	0	0	0	0	0
BA.V4.05	0	0	0	0	0	0
BA.V5.01	1	0	0	0	0	1
BA.V5.02	0	0	0	0	0	0
	6	2	0	1	9	18

Table 7 shows that RSS were found in twelve out of 17 buildings, where the half has only one shared space, four had two shared spaces and only one had 3 shared spaces. It could be said that RSS are not a common feature of the housing buildings analyzed in BA, yet openings mainly in toilets and corridors could influence indoor suitability for MTB droplets.

Figure 34: Roofed corridor in contemporary 'callejón'. Source: the author.

Table 8: Shared spaces between the affected and their neighbors in the housing building or compound: windows, skylights or openings to the outside in roofed spaces (excluding conventional doors)

Case study code	Shared Roofed spaces					Total
	Toilet or bathroom	Vestibule	Stairs	Hallway	Corridors	
BA.V1.01	0	-	-	1	1	2
BA.V1.02	0	-	-	-	1	1
BA.V1.03	0	-	-	-	1	1
BA.V2.01	-	-	-	-	-	-
BA.V2.02	-	-	-	-	-	-
BA.V2.03	-	-	-	-	-	-
BA.V2.04	-	1	-	-	-	1
BA.V2.05	0	-	-	-	1	1
BA.V2.06	-	0	-	-	-	0
BA.V3.01	-	-	-	-	1	1
BA.V3.02	-	-	-	-	1	1
BA.V3.03	-	-	-	-	1	1
BA.V3.04	-	-	-	-	1	1
BA.V4.01	0	-	-	-	0	0
BA.V4.02	-	-	-	-	-	-
BA.V4.03	-	-	-	-	-	-
BA.V4.04	-	-	-	-	-	-
BA.V4.05	-	-	-	-	-	-
BA.V5.01	0	-	-	-	-	0
BA.V5.02	-	-	-	-	-	-
	0	1	-	1	8	10

Table 8 shows that shared toilets lack of available openings or any other ways which could ensure continuous indoor air renewal. The exception are roofed corridors which are commonly provided with windows above entrance doors, most of the time opened to the streets and closed only at night for security reasons. Such condition would allow better wind flows to enter and create more possibilities for crossed ventilation and wind exchange.

Picture 6: Window above door in 'Quinta el Arca'

Space between buildings

The analysis in the neighborhood scale described the possible little influence of the urban form in BA to limit airflow and sunlight exposition in building facades facing those open spaces. Moreover, it pointed that open spaces were provided by each building typologies which almost always were the 'callejones'. Dimensions on shared spaces are analyzed through sections transversal sections made in 'callejones'.

Table 9: Studied building heights and distance between them. Average floor height: 4 meters.

Case study code	Building typology of the study case	Building floors	Number of floors of front neighbor	Distance between structures (meters)	Circulation space inside compound
BA.V1.01	Traditional hotel	1	1	1.2	Unroofed hallway
BA.V1.02	Contemporary 'callejón'	2	3	2.5	Unroofed hallway
BA.V1.03	Contemporary 'callejón'	1	1	1.5	Unroofed hallway
BA.V2.01	Traditional 'callejón'	2	1	1.8	Unroofed hallway
BA.V2.02	Traditional 'solar'	2	1	3	Unroofed hallway
BA.V2.03	Traditional 'callejón'	2	1	1.8	Unroofed hallway
BA.V2.04	Contemporary multistory 'callejón'	3	3	4.1	Unroofed hallway
BA.V2.05	Contemporary 'callejón'	3	1	2	Unroofed hallway
BA.V2.06	Contemporary 'callejón'	3	3	1.7	Unroofed hallway
BA.V3.01	Traditional 'callejón'	2	2	2.7	Unroofed hallway
BA.V3.02	Traditional 'callejón'	2	2	2.7	Unroofed balcony hallway and unroofed hallway
BA.V3.03	Traditional 'callejón'	2	2	2.7	Unroofed hallway
BA.V3.04	Contemporary 'callejón'	1	1	2	Unroofed hallway
BA.V4.01	Contemporary 'callejón'	1	1	1.5	Unroofed hallway
BA.V4.02	Traditional 'quinta'	2	1	2	Unroofed hallway
BA.V4.03	Traditional 'solar'	2	2	3	Unroofed balcony hallway and unroofed hallway
BA.V4.04	Traditional 'callejón'	1	1	2	Unroofed hallway
BA.V4.05	Traditional 'solar'	1	1	3.5	Unroofed hallway
BA.V5.01	Colonial 'quinta'	2	2	+	Unroofed hallway
BA.V5.02	Traditional 'callejón'	1	1	2	Unroofed hallway

Dwelling units inside housing compounds or buildings in BA present floor heights of four meters average, which are above the modern requirements for apartment buildings in Peru. This condition is taken to evaluate dimensions in the sections analyzed and deduct if open spaces are insufficient to gain natural ventilation and light. Table 9 shows the most constrained open spaces in red, which have less than two meters wide circulation spaces and higher front neighbors.

It should be mentioned that five out of the eight TB affected dwelling units with the tightest sections are located in two different collective housing buildings: traditional and contemporary ‘callejones’. For instance, BA.V1.02 and BA.V1.03 are houses probably built in recent decades located in the same housing compound, name ‘Quinta Alvarado’ which follows the spatial distribution of the ‘callejón’. These cases have different sections which dimensions are constrained by the unroofed hallway width in one and by the building heights in the other.

On the other side, BA.V3.01, BA.V3.02 and BA.V3.03 belong to the same collective housing unit, called ‘Quinta el Arca’, which is a traditional ‘callejón’. In this case, the spatial constrain is the balcony hallway on the first floor (SEE FIGURE NUMBER), which leaves an open space of 1.1 meter wide for natural ventilation and sunlight to reach the ground floor. This feature can also be observed in the case of BA.V4.03, which is also a traditional typology. The exceptional example is BA.V1.01, an structure probably belonging to an old hotel which has lost the roof in that part of the narrow hallway.

Figure 35: Section of callejón 'El Arca'. Source: the author.

Figure 36: Second floor in 'El Arca'. Source: the author.

The existence of more than one TB case in these two housing buildings might suggest that the spatial constrains of these typologies could create adequate settings for TB transmission. In the case of 'Quinta el Arca' the constrain is the same 'callejón' design, whereas for 'Quinta Alvarado', these constrains might depend on both the typology and shadowing effects of neighboring buildings.

5.3.3. Housing unit scale

Eleven collective housing buildings can be recognized as traditional typologies, whereas seven were new structures replacing the old ones in 'callejón' plots with, yet preserving the former spatial distribution. Almost all dwelling unit typologies could be considered as apartments with the exception of the hotel room and the studio. Despite being the most representative typology in BA, apartments presented a wide range of sizes: from three to seven rooms and 21 to 76 sqm distributed in one to three floors.

Table 10: Floor area per person and housing typologies

Case study code	Building typology of the study case	Current dwelling typology	Layout preservation	Condition of the structure	Approximate area	Number of dwellers	Floor area per person
BA.V1.01	Traditional hotel	Bedroom	Added mezzanine	Poor	14	9	1,6
BA.V1.02	Contemporary 'callejón'	Apartment	New typology	Acceptable	37	4	9,3
BA.V1.03	Contemporary 'callejón'	Apartment	New typology	Acceptable	21	5	4,2
BA.V2.01	Traditional 'callejón'	Apartment	Second floor added	Acceptable	21	4	5,3
BA.V2.02	Traditional 'solar'	Apartment	Second floor added	Poor	36	9	4,0
BA.V2.03	Traditional 'callejón'	Apartment	Added mezzanine	Acceptable	21	3	7,0
BA.V2.04	Contemporary multistory 'callejón'	Apartment	Preserved	Acceptable	32	2	16,0
BA.V2.05	Contemporary 'callejón'	Apartment	New typology	Good	76	5	15,2
BA.V2.06	Contemporary 'callejón'	Apartment	New typology	Good	36	5	7,2
BA.V3.01	Traditional 'callejón'	Apartment	Second floor added	Acceptable	36	4	9,0
BA.V3.02	Traditional 'callejón'	Apartment	Added mezzanine	Acceptable	42	4	10,5
BA.V3.03	Traditional 'callejón'	Studio	Preserved	Acceptable	28	4	7,0
BA.V3.04	Contemporary 'callejón'	Apartment	Second floor added	Acceptable	28	4	7,0
BA.V4.01	Contemporary 'callejón'	Apartment	New typology	Poor	21	2	10,5
BA.V4.02	Traditional 'quinta'	Apartment	Second floor and mezzanine added	Acceptable	48	10	4,8
BA.V4.03	Traditional 'solar'	Apartment	Preserved /Extended to neighbor	Poor	50	4	12,5
BA.V4.04	Traditional 'callejón'	Apartment	Second floor added	Good	50	4	12,5
BA.V4.05	Traditional 'solar'	Apartment	Added mezzanine	Poor	36	6	6,0
BA.V5.01	Colonial 'quinta'	Apartment	Added mezzanine	Poor	36	5	7,2
BA.V5.02	Traditional 'callejón'	Apartment	Second floor added	Acceptable	55	8	6,9

Nonetheless, the capacity of the cases analyzed seemed to be overpassed when looking at the available floor area rate per person. Table 10 displays all dwelling units rates below 16 sqm per person and half of them below 10 sqm per person. The highest rates belong to two contemporary built housing units, which are above 15 sqm per person. Contrarily, the worst cases have rates below 5 sqm per person, and belong mostly to apartments in 'callejones'.

Table 11: Measuring crowding in dwelling units

Case study code	Building typology of the study case	Number of dwellers	Number of habitable rooms	Dweller per room	UN-habitat	Argentinian National Institute of Statistics and Censuses	Includes productive space
BA.V1.01	Traditional hotel	9	2	4,5	Crowded	Critical Overcrowding	No
BA.V1.03	Contemporary 'callejón'	5	1	5,0	Crowded	Critical Overcrowding	Yes
BA.V2.06	Contemporary 'callejón'	5	1	5,0	Crowded	Critical Overcrowding	Yes
BA.V3.02	Traditional 'callejón'	4	1	4,0	Crowded	Critical Overcrowding	No
BA.V3.03	Traditional 'callejón'	4	1	4,0	Crowded	Critical Overcrowding	No
BA.V4.02	Traditional 'quinta'	10	3	3,3	Crowded	Critical Overcrowding	Yes
BA.V4.05	Traditional 'solar'	6	1	6,0	Crowded	Critical Overcrowding	No
BA.V5.01	Colonial 'quinta'	5	1	5,0	Crowded	Critical Overcrowding	Yes
BA.V1.02	Contemporary 'callejón'	4	2	2,0	No	No	Yes
BA.V2.01	Traditional 'callejón'	4	3	1,3	No	No	No
BA.V2.02	Traditional 'solar'	9	3	3,0	No	No	No
BA.V2.03	Traditional 'callejón'	3	2	1,5	No	No	No
BA.V2.04	Contemporary multistory 'callejón'	2	2	1,0	No	No	No
BA.V2.05	Contemporary 'callejón'	5	2	2,5	No	No	No
BA.V3.01	Traditional 'callejón'	4	3	1,3	No	No	No
BA.V3.04	Contemporary 'callejón'	4	3	1,3	No	No	No
BA.V4.01	Contemporary 'callejón'	2	1	2,0	No	No	Yes
BA.V4.03	Traditional 'solar'	4	3	1,3	No	No	No
BA.V4.04	Traditional 'callejón'	4	3	1,3	No	No	No
BA.V5.02	Traditional 'callejón'	8	3	2,7	No	No	No

UN-Habitat and ANISC crowding indexes consider 'crowded' and 'critically overcrowded' 8 dwelling units, which presented more than three inhabitants per habitable room. Moreover, six of the dwelling units had productive spaces or workshops inside the houses and four of them could already be considered as overcrowded when comparing with crowding measure indexes. Having other uses besides residential ones in the study cases, might worsen crowding conditions, because the households may use the already limited space they have for storage, working space and hosting laborers.

Noteworthily, six out of the eight most crowded dwellings are old structures belonging to 'quintas' or 'callejones' collective housing typologies, from which five had modifications like added mezzanines or second floors. Furthermore, inner extensions were commonly made to gain living space when room heights would allow it. Evidence of the latter is that twelve dwelling units presented some kind of structural modification or extension to add bedrooms or toilets.

Figure 37: Section of crowded dwelling in BA. Source: the author.

Figure 38: Crowded interior of dwelling, showing a mezzanine. Source: the author.

Crowding conditions and insufficient dwelling space is a common characteristic of the houses inquired in BA. Seven interviewees claimed to have at least one relative which have had TB in the past, though only two suggested that contagion could happen in their dwellings. Nevertheless, other settings for TB contagion were suggested by the interviewees. The non-residential settings mentioned included workplaces, a health center, and a study center. Moreover, three affected were described by their relatives as having alcohol addiction problems, and suggested that contact with fellow alcoholics in street gatherings or bars could have been the origin of contagion.

Openings and 'double-sided' ventilation

Similar with the cases in CSC, some dwelling units in BA had windows without closing panels. Despite the reasons dwellers could have to leave windows in this condition, it seems that this happens when security or privacy are not directly compromised, for instance in the case of windows above doors. The latter could be practical to gain sunlight and wind flows indoors, however it could be insufficient for effective air renewal, especially if those are the only openings in the dwelling units.

Table 12: Number of windows or other openings (excluding doors) per habitable room and cross ventilation possibilities among dwelling units in BA

Case study code	Building typology of the study case	Current dwelling typology	Number of bedrooms	Bedrooms with at least one openable window or other	Number of openable windows in social space	Number of floors	Cross ventilation possibilities of the layout
BA.V1.01	Traditional hotel	Bedroom	2	2	-	1 + mezzanine	No
BA.V1.02	Contemporary 'callejón'	Apartment	2	1	1	2 + rooftop	Yes, but limited. Through windows and skylight in first floor
BA.V1.03	Contemporary 'callejón'	Apartment	1	1	-	1 + mezzanine	No
BA.V2.01	Traditional 'callejón'	Apartment	2	2	1	2 + rooftop	Yes but limited. Only if bedroom door in the first floor is open
BA.V2.02	Traditional 'solar'	Apartment	2	1	1	2	Yes but limited. Only if bedroom door in the first floor is open
BA.V2.03	Traditional 'callejón'	Apartment	1	1	0	1 + mezzanine	No
BA.V2.04	Contemporary multistory 'callejón'	Apartment	1	1	1	1	Yes, through window in living room to interior unroofed patio
BA.V2.05	Contemporary 'callejón'	Apartment	1	0	1	3	No
BA.V2.06	Contemporary 'callejón'	Apartment	1	1	1	3 + rooftop	Yes but limited. Only in the second floor and limited size of holes
BA.V3.01	Traditional 'callejón'	Apartment	2	2	1	2	Yes but limited. Through entrance door and skylight. Only when entrance door is open in the ground floor
BA.V3.02	Traditional 'callejón'	Apartment	1	1	1	1 + mezzanine	Yes. Through skylight and window above door
BA.V3.03	Traditional 'callejón'	Studio	1	-	1	1	Yes, but limited. Through window above door and skylight when kitchen door is open
BA.V3.04	Contemporary 'callejón'	Apartment	2	2	1	2	Yes, but limited through window and skylights in the first floor
BA.V4.01	Contemporary 'callejón'	Apartment	1	0	0	1	No
BA.V4.02	Traditional 'quinta'	Apartment	2	2	1	2 + mezzanine	Yes, but limited. When entrance door is open in the ground floor
BA.V4.03	Traditional 'solar'	Apartment	2	1	0	1	Yes but very limited. Through skylight in kitchen when entrance door is open
BA.V4.04	Traditional 'callejón'	Apartment	2	2	0	2	Yes, but limited. In the first floor through window in the bedroom and skylight
BA.V4.05	Traditional 'solar'	Apartment	2	0	1	1 + mezzanine	No
BA.V5.01	Colonial 'quinta'	Apartment	1	1	0	1 + mezzanine	Yes, but limited. Through window above door and window in bedroom when open

BA.V5.02	Traditional 'callejón'	Apartment	2	1	1	2	No

Table 12 shows seven dwelling units with at least one bedroom without window, while no windows in social spaces were presented in five cases. All of the latter were apartments, yet there was no clear distinction by collective housing typology. Additionally, air renewal could be ensured only in two cases where sufficient openings are provided in opposite sides without restrictions. Distinctly, seven cases would not have any possibilities for crossed ventilation, and the eleven left would have some limitations, for instance when depending on entrance doors to be opened or when only having the conditions in one of their floor levels. Lack of indoor air renewal possibilities through crossed ventilation and insufficient sunlight exposure indoors, could increase the risk of MTB droplets to remain for longer periods on air. Hence, the probabilities for contagion in the seven dwellings with the most limitations might be high.

5.3.4. Urban planning proposals and approaches to improve conditions in BA

Currently, there is an urban renovation proposal made by PROLIMA, a public institution which seeks to plan renovation and conservation projects for the old town of Lima. BA is included in the plan, nevertheless among the goals of such project there is no explicit mention to the public health problem, especially related with TB. The masterplan has clear focus on the restoration of the monumental part of the historic district, and explicitly includes the argument that touristic activities are one of the pillars and reasons to make this development. The strong focus on the image can be de noted, for instance, in design layouts for the exact reproduction of furniture from old pictures. Moreover, the local academia and practitioners have heavily criticized the plan, naming it 'the façade plan', after its strong focus on rescuing the former urban image of the old town in the early 20th century, and the weak approaches to tackle social issues in the area.

5.4. Discussion

The housing environment in CSC and BA, contributes to increase the risk of TB transmission

The results denote that dwelling units studied in BA and CSC presented physical characteristics associated to environmental factors which increases the risk of TB transmission. As it was explored in chapter 4, spatial constrains in dwelling units, their collective housing typology and their surroundings, could obstruct or limit sunlight and natural ventilation provision for indoor spaces. In CSC, street sections show tight alleys and similar building heights, which could promote the creation of suitable indoor environments for MTB in dwellings. Shading effects caused by neighboring buildings can prevent direct sunlight to reach small open spaces pockets and indoor spaces at ground level to 'clean' the air out of bacterium (Lai et al., 2013, p. 41). Adequate ventilation rates may also be limited, preventing indoor air renewal and the consequent dilution of airborne microbes. However, airflow could depend from other environmental factors and physical phenomena, which require specialized studies on its behavior to prove this point, particularly for the case of slums.

Contrarily to CSC, healthy conditions in indoor spaces of dwellings in BA would be limited by the characteristics of collective housing typology in which they are, rather than external factors. The sections showed tight proportions in most of the 'callejones', independently from the building age. This suggests that the spatial constraints of the typology itself, which is strongly influenced by the plot shapes, have a similar effect of limitation of sunlight and ventilation as the external factors do in CSC.

Furthermore, the clustering of active TB affected and cured patients in 'callejones', might suggest that these were the settings of contagion, despite that only two of them presented more than one active TB case in parallel. A possible explanation for the prevalence of TB cases in 'callejones', is the high probability of contact between residents and the affected or inhalation of MTB droplet nuclei remaining in the air, in shared spaces presenting environmental factors. The analyses of shared spaces in collective housing buildings in both study areas demonstrated shared that areas are most commonly roofed corridors and toilets, which were often shaded and lack of openings to the outside. Such spaces require special attention from urban authorities and epidemiologists, because they are most likely to be suitable environments for TB bacilli preservation, and the continuous use by residents and visitors might perpetuate TB incidence in the building or could export it to other neighborhoods. Further investigations of TB incidence among residents in collective housing buildings in CSC is needed to prove this point, because few interviewees pointed out former or active TB cases among their neighbors, probably because of stigmatization.

Consequently, most of the dwelling units surveyed in both areas are high-risk settings for infection. It can be said that single windows in one wall and habitable spaces without windows were a common feature of houses. Whereas the effects of enclosed spaces are already explained, openings in one wall would only create 'Single-sided' ventilation, which does not ensure high ventilation rates and indoor air renewal (Atkinson and WHO, 2009, p. 28). Likewise, the layouts analysis showed that few houses had opportunities for 'double-sided' ventilation in habitable spaces, despite their different typologies. It can be assumed that spatial constrains at their best, could limit indoor spaces to diffused light, which could have a slower effect on eliminating airborne microbes like MTB (Hobday and Dancer, 2013, p. 276). In addition to the latter aspect, dustiness and dampness in dwelling units in BA and CSC might present further advantages for microbes to survive and be inhaled by occupants, or to generate further respiratory problems (Keall et al., 2012).

Densification and current overcrowding

The maximization of dwelling space in both neighborhoods limited heavily the performance and availability of openings and open spaces, ensuring dark and badly ventilated spaces. Current physical limitations of dwelling units had been created by their occupants, probably responding to the need for dwelling space in well-located and cheap areas. The results imply that residents of BA and CSC had spatial constrains which limited their dwelling sizes. On the one hand, dwelling units of 'callejones' in BA were probably designed to host singles, couples or small households. The increment of the number of household members pushed the families to transform the existing spaces, performing inner extensions in high ceiling spaces, i.e. mezzanines, room subdivisions, and second floors, or external extensions when the roof was accessible. Likewise, workshops and storages existing in some houses can encroach more the habitable spaces, worsening crowding conditions.

On the other hand, density of housing, fully occupied plots, and small dwelling units in CSC, are most probably the result of the high demand for habitable space. Similarly, hotel-like buildings with rooms for rent and 'callejones' built in subdivided plots, suggest that owners sought rentability of the space. Furthermore, crowding conditions among the households surveyed are alarming and complete the adequate factor combination for a suitable setting of contagion. In both cases household sizes exceed the capacities of the spaces they inhabit, resulting in appalling crowding conditions in half of the dwelling surveyed, with more than three inhabitants per habitable room.

Further determinants to consider in current approaches

The combined conditions mentioned above, with social and biological factors, may explain the endemicity of TB in BA and CSC. The high exposition to airborne transmission of the household members in the studied houses implies a high probability of LTBI. Moreover, high levels of humidity in the air during winter in Lima, high levels of air pollution and side effects of the lack of access to adequate sanitation and clean water, are among other environmental factors which could play a role in TB epidemic in the study areas. Likewise, the continuous population movement inside, within and outside populous endemic areas, including the arrival of new rural-urban migrants and Venezuelan refugees, adds an extra layer of complexity for epidemiological control. The possible contribution of such factors and the spatial determinants explored by this inquiry implies that environmental factors require much more attention by researchers, policymakers, and government agents, to create multi-level and multi-sectoral strategic solutions, towards ending TB by 2030. Therefore, current biomedical foci of drug treatments, awareness-raising, and social aid may not be sufficient to stop the burden towards reaching the goal of ending of TB by 2030.

6. Conclusions

6.1. Recommendations

This research has outlined the struggle against TB in Peru and sought to explore the role of the built environment, particularly of slum dwellings, on transmission and prevalence in the study areas. It has been suggested that including actions which tackle the environmental and exposure factors, will reinforce current TB control measures into a more integral and effective strategy. The following steps, therefore, would be to consider which kind of interventions are more suitable for the study areas and their social context, how can these be strategically organized to have the greatest positive impact, and how can negative effects be prevented. On the first place, the allocation of necessary resources for public investment in integral actions in slums is required, considering the outrageous amount of money in the overall annual expenditure on the struggle against TB in Peru, and the economic stability of recent years. Secondly, an adequate scenario should be set to include and promote health values into the current discussions around urban topics at the national level. The public sector can be essential for health advocacy in other sectors of society. For instance, the education role of civil organizations and academia could be enhanced for advocating health values to students, professionals, and workers in the fields related to urban development (WHO, 1989). This strategy could be taken further in creating a culture of disease prevention and creation of healthy environments among citizens, through strengthening current good practices and empowering potential change agents.

A call for an alliance to all sectors of society towards the end of TB could present an opportunity to benefit the national-level economy, through the improvement of health conditions of slum dwellers (Forum on Microbial Threats et al., 2018, p. 67). Such opportunity could also include solutions for tackling the social determinants of ill health and other multiple health improvement criteria, to integrate with environmental measures and biomedical strategies (Corburn and Sverdlik, 2017, p. 8; Forum on Microbial Threats et al., 2018, p. 56; Hargreaves et al., 2011; Ortblad et al., 2015). Thus, a broader strategy should be designed for multisectoral and multilevel actions, through the involvement of the relevant sectors of the government, and require the active participation of the resident associations and community-based organizations. Likewise, a broader vision of the improvement of public health in urban areas should not be limited to the 'hot spots' of TB. Although the urgency of the epidemic calls for action primarily in those areas, other slums with similar characteristics should be spotted and comparable strategies may be applied to prevent epidemiological risks. Consequently, the allocation of the necessary resources may be understood as a social investment, which would represent a long-term return in the overall wellness of the society.

6.1.1. Improvement of the built environment

It can be assumed that to reduce the incidence of TB in slums through interventions in the built environment, the environmental and exposure factors which increase the probability of infection should be tackled. These interventions should be directed to improve conditions in housing and other potential high-risk settings inside and outside the neighborhoods, adapting to different physical conditions. The heterogeneous morphology of the slums in Peruvian cities, demands adapted physical and social intervention strategies. This inquiry suggested Barrios Altos and San Cosme Hill as representative cases of slums in traditional areas and hills respectively, and displayed their different urban forms and housing typologies.

Moreover, if crowding conditions are to be eliminated, some relocations should be carried on to re-densify and distribute population to healthier environments, especially in areas where preconditions are adverse. However, the right of the residents to stay in their dwelling areas should be recognized and when new housing projects are required, these should be developed in the same neighborhoods if not in the same plots. For instance, in the case of Barrios Altos, it is clear that upgrading interventions should be focused on 'callejones', which could require relocations, especially for the case of historic 'callejones'. The latter are part of the fading built heritage in the area, and require stabilization to ensure permanence over time and safety of their residents. Thus, demolition and hard physical interventions are not recommended in such settings. Instead, the relocation of large households living in crowding conditions to new healthy housing projects in the area could be the best option to reduce TB incidence in these typologies. To free space for new healthy housing projects, it would be necessary to intervene storages and warehouses illegally built in residential areas of BA, and seek their relocation in other suitable places. This kind of procedures demand further studies and will have implications in urban policies. Likewise, contemporary 'callejones' which have informally built housing with poor conditions could present an opportunity to develop new housing spaces to host the same residents. For such interventions, productive spaces should be included as some of the households depend on these spaces to generate their income.

Similarly, relocations could be carried on in crowded bedrooms and studios in CSC, and physical interventions to increase ventilation rates, sunlight, and ensure environmental safety, might be performed in housing buildings when possible. Such measures should be focalized in shared spaces in collective housing of both neighborhoods, as suggested in the previous section. For the case of CSC, bold physical interventions could be required in the neighborhood level, to provide open space from which the packed dwellings could benefit. The WHO has recommended that selective demolitions should be done when possible, to create healthier residential environments (WHO, 1988). Therefore, tactical inclusion of open space and the former upgrading project of PLAM 2035, must be contemplated. Likewise, the improvement of clean water provision and sanitation services in the study cases, could consequently enhance living conditions and prevent further erosive effects on the health of dwellers, thus adding a positive factor to reduce TB incidence.

On the other side, the enhancement of indoor air quality through mechanical means could not be a suitable alternative for slum settings. The installation of mechanical ventilation systems and UV light lamps in the space with high risk of contagion, i.e. shared spaces, could demand constant maintenance and may be ineffective on preventive the development of active TB, which depends on other health-erosive conditions, for instance, undernourishment and other co-morbidities. Therefore, this alternative might be considered as palliative and highly probable to be ineffective on reducing the burden of TB.

6.1.2. Implications in urban policies

To perform the actions mentioned above, it would be necessary to develop or change current planning policies. The first measure would be to reconsider former integral plans and proposals which were overpassed, mainly because of political rivalries. In this context, the recommendations and ideas presented in the PLAM 2035 should be picked to serve as starting points to design future interventions. Secondly, housing could be understood as an environment which can foster the health of the inhabitants. That concept implies the revision of the current parameters for housing and the inclusion of new ones into the existing Peruvian building regulations. For instance, occupancy, ventilation and sunlight minimum rates should be specified and the ways to achieve them must be explained clearly. The application of such regulations in existing buildings of slums could be flexible, nonetheless, occupancy rates should be carefully controlled to avoid crowding.

Thirdly, housing opportunities must be provided for those who cannot afford larger and healthier dwelling spaces. This might imply a switch from the current market-driven social housing approaches in the country, to a pro-poor housing strategy. Tenure security should be guaranteed and protective measures could be taken to avoid gentrification in the neighborhoods improved, which are conveniently located, and prevent that displaced populations return to similar conditions in areas where housing prices are lower. The latter aspect could require social intervention in the housing market, as advised by the WHO, to provide affordable and flexible options in close areas or the same neighborhoods intervened (WHO, 1988). Tackling tenure insecurity could relief slum dwellers from further stresses which could affect negatively their health (Harpham, 2009).

Moreover, the active participation of the residents, probably through the legal figure of the resident associations, and community-based organizations, must be assured. This involvement will result in greater acceptance and accuracy of the solutions proposed by technicians. In that context, the guidelines of the PSUP (Participatory Slum Upgrading) proposed by the UN-Habitat in the neighborhood scale, or participatory design strategies, i.e. co-housing, might be good models of reference to shape the interventions mentioned above. These strategies may be thought considering the applicability in other slum areas of Lima and other cities, while further insight and control measures over the densification of existing slums and the prevention of new squatting settlements must be taken. This would easy the management and identification of the needs of slum dwellers. Lastly, if the self-help housing scheme is still going to be the approach to aid the housing shortage for the poor, it might be convenient to advocate for health principles of design through awareness raising, capacitation and technical assistance.

6.1.3. Improvement of socioeconomic conditions

It was suggested that the improvement of socioeconomic conditions of slums dwellers could increase their resilience to infectious diseases like TB over time. Parallel actions to the improvement of the built environment must be taken to achieve integral and long-lasting solutions for current ill-health burdens. The local economy could be strengthened through adequate strategies, i.e. by offering capacitation for local entrepreneurs and existing businesses or by ensuring employment opportunities in the labor market. Moreover, the upgrading projects could present an opportunity for training of residents to become, for instance, health promoters involved actively in the transformation of their contexts, whereas earning a wage to support their families. Also, these measures could be helpful to increase the economic capacity of the households to afford healthy housing (WHO et al., 2018, p. 29). The latter aspects require further studies on how can adequate strategies for socioeconomic development be implemented in Peruvian slums, i.e. to achieve formalization. Likewise, the sustainability of the new healthy housing projects must be guaranteed through empowering and strengthening residents associations and community-based organizations, to foster appropriation and enhance self-management capabilities. Finally, ensuring access to adequate health and education services is essential for socio-economic development, in the scope of improving public health, and actions towards this aim should be consciously planned and implemented.

6.2. General conclusion

Biomedical strategies and drug treatments could be accompanied by upgrading of the built environment and reinforced by the improvement of socioeconomic conditions to ensure an effective plan on alleviating TB burden among slum dwellers in the study cases, and similar areas in Lima. Projects of this type could set a precedent for the integral approach proposed by the 'End TB Strategy', which could help to reach the goal by 2030. Finally, considering the recent economic and social stability in Peru, it could be the appropriate moment to switch paradigms and prioritize public health through urban development, to enhance the capacities of the human capital through integral and sensible projects, strengthen urban economy, and achieve a more equitable city.

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