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Socio-physical liveability through socio-spatiality in low-income resettlement archetypes - A case of slum rehabilitation housing in Mumbai, India

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ABSTRACT

This study looks into the socio-physical liveability through socio-spatiality in low-income settlement archetypes. Paradoxically, recently mushrooming slum rehabilitation housing which have delivered secured tenure to its inhabitants, face threats of being deserted from lack of socio-physical liveability. Recurring of informality issues has advocated to investigate the reasons behind the 'rebound' phenomenon. This study explores the efficacy of socio-spatiality and its linkages with socio-physical liveability, taking Mumbai slum rehabs as case study. A comparative analysis of the current built-environment indicators and liveability status of major informal archetypes was performed, followed by analyses of the socio-physical problems associated with it. A critical evaluation of the rehabilitation housing of Mumbai highlights the problems caused by the current dense built-environment design. Reflecting on global instances, this article demonstrates the significance of socio-spatiality and suggests environmentally sustainable indicator-based built-environment recommendations, which if implemented in the forthcoming slum rehab housing planning, would enhance well-being and liveability among the low-income sector in future. While analysing the 'rebound' phenomenon, this study delivered a heuristics of socio-physical liveability, built-environment and their respective indicators. This method would aid the architects, planners and policymakers in reshaping the forth-coming built-environment while safeguarding the socio-physical liveability of the low-income sector.

1. Introduction

Liveability, the concept which connotes the ability of living space to support well-being or quality of life is an integrally crucial factor in urban areas. Studies on the concept of 'liveability', being devoid of any precise and universally accepted definition, embraces cognate notions such as sustainability, quality of life, the 'character' of place, well-being and health of communities. However, liveability remains a question in low-income neighbourhoods across the world. Insecure housing occupancy and unaffordability issues turn living conditions detrimental to the unprivileged society. Such deplorable living conditions include poorly built housing structure on inferior contaminated or disaster-prone sites and dearth of basic services. This exposes the low-income communities disproportionately to greater physical and social risks (Govender, Barnes, & Pieper, 2011). A study in Nigeria observed 'disgraceful housing characteristics, poor economic vitality, limited neighbourhood facilities and unsafe situations' in the low-income neighbourhoods (Mohit & Iyanda, 2016).

Poor liveability in low-income neighbourhoods gets aggravated by the phenomenon of unprecedented urbanization which is estimated to reach 70% by 2050 (Skalicky & Čerpes, 2019). In response to extreme urbanization and while approaching efficient planning, apart from the classical method of slum eradication, the slum improvement policies initiated in-situ up-gradation, which aimed at delivering basic services to the informal unplanned settlements. Additionally, in an attempt to develop 'slum-free' cities, the affordable housing authorities, adopting neo-liberal approaches transformed metro-cities into hyper-dense low-income vertical towers (Bardhan, Debnath, Malik, & Sarkar, 2018). The slum dwellers shifting to these high-rise rehabilitated apartments for the first time were provided with legal tenure in addition to basic services and free housing. Yet, the slum resettlement and rehabilitation policies fail resulting in the 'rebound' (Debnath, Bardhan, & Sunikka-blank, 2019) and 'poverty recycling' phenomenon (Jones, 2017; Minnery et al., 2013; Nagarajan, 2017; Sholihah & Shaojun, 2018).

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Sociological and anthropological field studies on adverse effects resulting from forced displacement identified 'impoverishment' as a 'common factor' and a 'complex process' (Hong, Singh, & Ramic, 2009). 'Dismantled production systems, disorganised residential communities, dispersed kinship groups, destroyed cultural identity, disrupted labour markets and trade linkages and loss of mutual help arrangements' are major consequences of involuntary displacement (Cernea, 1995, 1997), that leads to the impoverishment of the displaced population.

Among these socio-economic contributors of rebound phenomenon, 'loss of socio-physical liveability' remains the most under-researched factor. Often, the slum resettlement policies fail to critically address significant liveability parameters, that include socio-cultural, socio-economic and socio-spatial aspects of the low-income sector (Bardhan, Sunikka-Blank, & Haque, 2019; Sunikka-blank et al., 2019). Mostly the researches are restricted in the identification of failure of slum resettlement policies. Particularly, investigation of the parameters that affect socio-physical liveability of the slum resettlements is currently underventured. Therefore, a systematic process-driven assessment of these parameters eventually contributing to the rebound phenomenon is exigent.

In an unprecedented urbanization scenario, built-environment often turns as a significant parameter. The impact of built-environment on the indicators of social liveability such as privacy quotient, safety, security and social cohesion needs to be investigated. Furthermore, exploration of the effect of built-environment on physical liveability indicators like air quality, ventilation and thermal comfort, which directly affect occupant health is also vital. Recognising the key roles played by the built-environment design in modifying the socio-physical liveability especially in the low-income neighbourhoods has the potential to contribute to innovative bottom-up approaches to formulate more effective slum rehabilitation housing (SRH) design policies. Moreover, current habitat policies require an efficacy-evaluation tool for assessing socio-physical liveability in the present low-income housing with socio-architectural complexities.

The novelty of this study lies in adopting a liveability perspective on housing design and household practices taking SRH in Mumbai, India as a case study. The assessment technique applied here elucidates *how reshaping the built-environment might restructure the socio-spatiality of the slum resettlements and enhance the liveability of the low-income strata of population?* The research aims to a) understand the built-environment differences in low-income typologies in Mumbai, as a comparative analysis would enable in identifying the differences in housing design as well as liveability quotient, b) how built-environment design has changed the occupants' practices and behaviour, and how c) that affects the socio-physical liveability and d) which indicators of the built-environment influence liveability. This study, by beholding the notion of socio-physical liveability facet of the slum resettlement policies, investigates into the socio-spatial nexus thus, eyeing into the current blind-spot in the slum resettlement policies. The inferences from this study would aid in formulating the low-income habitat planning guidelines in cities of developing nations especially in the global south.

The following part of the paper is structured as follows. The global theoretical assumptions and literature review are described in Sections 2 and 3. The case studies and the methodology are described in Sections 4 and 5. Section 6 represents the analysis of the current status of the low-income settlement archetypes, Sections 6.1 and 6.2 on socio-physical liveability assessment in low-income archetypes. Section 7 tests and discusses the hypothesis, and deliver recommendations. Section 8 concludes.

2. Socio-spatiality and impoverishment of displaced population: global scenario

Henri Lefebvre, philosopher and social theorist in his book 'The Production of Space' (1974), while explaining theories of spatial justice and socio-spatial architectonics recognised the integrally crucial relationship between '*the body and its space, between body's deployment in space and its occupation of space*'. He explains that '*…each living body is space and has its space: it produces itself in space and it also produces that space*'. Space, according to Lefebvre's view is '*at once a precondition and a result of social superstructures*' (Lefebvre, 1991). He inveighed against treatment of space as a mere milieu or content and explicated space as the *interlinkage of geographical form, built-environment, symbolic meanings and routines of life*. Lefebvre's spatialisation also extends not only from representations of space to representational space, but from absolute space to abstract, contradictory and differential space (Fuchs, 2019; Molotch, 2020; Ingen, 2003; Donald Nicholson-smith, 2019).

Nevertheless, inefficient space design and poor planning, operation and monitoring during development-induced and forced internal displacement has advertently caused socio-spatial injustice leading to degenerated spatialisation and impoverishment and disruption of social fabric among marginalised groups (Hong et al., 2009). This section intends to address the extremity and scope of this problem by comparatively reviewing former involuntary resettlement developments. Additionally, from the epistemology, this study further highlights socio-spatiality as an alternative facet of resettlement that can possibly notify a set of criteria to be used as an assessment tool for national policies centring involuntary-resettlement.

Antecedent displacement theories like four-stage Scudder-Colson diachronic theoretical model on development-induced involuntary settlement (Cernea, 1995) turned as a comprehensive socio-economic model which focussed on stress dimension of the resettled population. However, these theories failed to place the onset of impoverishment and the process of escaping the impoverishment among the displaced population. In this backdrop, the theoretical construct of Impoverishment Risks and Reconstruction (IRR) Model proposed by Cernea (1997) undertook a diagnostic approach in identifying the key risks in displacement, which are as follows: "(a) landlessness; (b) joblessness; (c) homelessness; (d) marginalization: (e) food insecurity; (f) loss of access to common property resources; (g) increased morbidity; and (h) community disarticulation."

The past efforts to identify the reasons behind the failure of slum resettlements were primarily focussing on the socio-economic parameter. Public housing programmes in developing nations like Bandung, Indonesia created serious problems of social displacement and disruption and imposed precarious financial burden for the residents of slum and squatter settlements, which appeared incompatible in accommodating the way of life practised in Kampung adaptive urbanism contexts (Jones, 2017). In Jakarta, Indonesia the induced displacement caused loss of employment, deprivation of social status, increased marginalization, increased electricity-burden and transportation costs, food insecurity, increased morbidity and social disarticulation (Sholihah & Shaojun, 2018). Quality of public housing was also found low in Lagos state, Nigeria (Ilesanm, 2012). In the case of Seoul, Korea, the slum rehabilitants were forced to depend more on public assistance to repay housing rehabilitation loans (Dennis, 1990).

Similar delusions were observed in Indian metro-cities like Chennai and Mumbai. While in Chennai the lack of consideration of psychology, living culture and spatial requirements of the slum dwellers resulted in the abandonment of government low-income housing (Nagarajan, 2017). In Mumbai, the rehabilitated vertical towers claim to deliver infrastructure to the slum-dwellers, yet the rehabilitated residents were observed to ultimately rent out or leave the apartments and shift back to other slums, thus proliferating more slums (Bhide, Shajahan, & Shinde, 2003; Debnath et al., 2019; Restrepo, 2010).

A recent critical review by Aboda, Mugagga, Byakagaba, and Nabanoga (2019) identified loss of social networks, increased infestation, reduced access to land and low food security as risks of the development-induced displaced population in developing countries. However, while challenging the most significant theory of conceptualization of involuntary resettlement i.e. IRR theory, Wilmsen, Adjartey, and Van Hulten (2019) reported that '*the model is useful for*

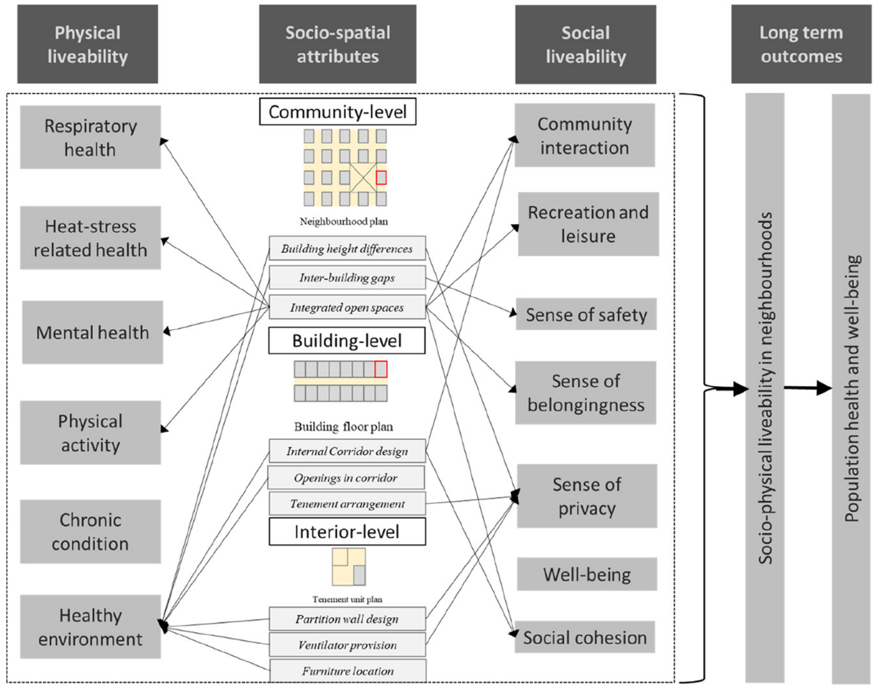


Fig. 1. Causal pathway of socio-physical liveability, encompassing determinants, and long-term outcomes.

identifying material losses, but fails to illuminate more complex social fragmentation, extra-local dynamics and relationships of power.' While the IRR model looks at various facets of well-being in slum rehabilitation, there is a lack of understanding of the comprehensive socio-physical liveability.

Among varying socio-economic displacement theories, the IRR model suggests that reconstructing and improving the livelihood of the displaced would require explicit strategies suchlike "from homelessness to house reconstruction" (Aboda et al., 2019; Cernea, 1997). Yet, the rehabilitation settlements are not permanent solutions to the shelter problems of the poor as often slum clearance leads to recycling of poverty (Dennis, 1990).

Lefebvre, through his production of space, insisted that it was wrong to conceptualize space as an autonomous determinant, separate from the structure of social relations. Rather space should be considered as social product of human body (Stewart, 1995). The philosophic-epistemological notion of 'social space' has been repeatedly used by the sociologist to capture the spatial forms of all social relations and it is this social-space and its interaction with socio-physical liveability that is the focus of the study. To the existing theoretical construct, this study adds 'loss of socio-physical liveability' as another key-risk of the impoverishment of the displaced population.

Therefore, there needs to be an in-depth study to understand the socio-spatial efficacy of the SRH in terms of socio-physical liveability. This research attempts to expand on the identification of built-environment that influences socio-physical liveability. This study also develops explicit measurement strategies that would ultimately aid in recovering the rehabilitants from impoverishment.

3. Built-environment and socio-physical liveability: interlinkages

Theories suchlike "Maslow's pyramid of needs", Lefebvre's "The production of space" and the "Mercer Quality of Living indicators" synthesize the significance of geographical form, built-environment, housing, recreation, socio-cultural and environmental setting in promoting improved social relations and liveability from the social and physical viewpoint. Lefebvre's theory also brings out *architecture, human densities, locational relations* as key structural forces of social space (Donald Nicholson-smith, 2019). More recently, Clements-croome, Marson, Yang, and Alraksinen's (2017) SuBET planning tools emphasised that *people, products, structure* and *processes* are major indicators for liveability measurement, where the term *products* refer to '*building quality, materials and fabric*'. These theories elucidate that social and physical liveability is a subject of the urban built environment.

Tapsuwan, Mathot, Walker, and Barnett (2018), while determining the preferences for sustainable, liveable and resilient neighbourhoods presented a list of neighbourhood features under social, neighbourhood safety, healthy environment, economy, community, and accessibility and connectedness categories. Badland et al. (2014) had listed 11 domains of natural environment, crime and safety, education, employment and income, health and social services, housing, leisure and culture, local food and other goods, public open space, transport, social cohesion and local democracy while measuring urban liveability. Nevertheless, while a holistic concept of liveability was presented in these recent researches, the distinct and comprehensive impact of built-environment indicators on socio-physical liveability needs further attention.

A systematic review approach was charted as a part of a holistic goal that seeks to identify the built-environment indicators that would aid in modifying the socio-physical characteristics of space. Owing to the lack of adequate consideration of liveability in Indian urban planning and habitat design policy context, this study initiated by underpinning a list of policy-relevant indicators related to socio-physical liveability, health and well-being, that are evidence-based, specific and quantifiable, measurable at neighbourhood, building-envelope and indoor levels, and relevant to Indian urban planning policy context. A keyword-based search with appropriate combinations of terms like '*liveability, built-environment, indicator, measure, social liveability, health, well-being*' were utilised to derive at 47 eligible articles that directly focussed on the socio-spatiality and socio-physical liveability interlinkages. While the evidence-based domains of social liveability included community interaction, recreation, leisure, social cohesion, sense of belongingness, safety, privacy and well-being; the physical liveability incorporated the domains of healthy environment, respiratory, heat-stress related and mental health. The built-environment indicator selection framework involved a set of criteria- i) whether the indicator was significant to social and/or physical liveability in urban environment, ii) whether the indicator was specific and quantifiable (e.g. presence/absence, specific value or threshold etc.), and iii) whether the indicator was relevant to Indian urban planning and habitat design policy context, to recognise the pertinent indicators.

In this milieu, Zhou, Wang, Chen, Jiang, and Pei (2014) suggested a three-step procedure for built-environment design investigation: (1) community level, (2) building level, and (3) interior level (see Fig. 1). The review yielded a taxonomy of 25 indicators under 'integrated open space', 20 indicators under 'built-form', and 12 indicators under 'street network' to justify the interlinkage between community level built-environment design and socio-physical liveability. Additionally, four and 12 evidence-based indicators were charted under 'building corridor' and 'dwelling unit condition' respectively to establish the impact of building and interior level built-environment on socio-physical liveability (see Appendix 1 representing the concise list of built-environment indicators).

Once identified, the final set of indicators was selected based on the criteria- 'whether the indicator is promising as it meets all or most of the criteria'. Based on Appendix 1, the second-stage review identified 9 distinct indicators considered to be important components affecting socio-physical liveability (Fig. 1). The designated indicators were building height differences, inter-building gaps and integrated open spaces at the community level, internal corridor design at the building level and partition wall, ventilator and furniture location at the interior level.

Table 1 discloses a comprehensive discussion concerning the association between final selected built-environment design variables (derived from Appendix 1) and socio-physical liveability.

Understanding the vocabulary, concepts, the epistemology of built environment and socio-physical liveability linkages through aforementioned studies gives urban designers and planners a powerful utilitarian tool and methodology to design by coupling integrated urban built-form and socio-physical neighbourhood liveability strategies.

4. Study area: existing low-income archetypes in Mumbai

Mumbai's housing typologies are often described as a consequence of slum improvement and affordable housing policies (CRIT, 2007). Affordable housing in Mumbai has evolved into three major archetypes of low-income settlements -i) traditional slums, ii) chawls built either by government agencies or by private initiatives and iii) slum rehabilitated housing (SRH) built with private initiatives. These differ primarily in the tenure security, physical structure, ratio of public and private space, and dwelling's relation to the adjacent street. At the global level, while the developing countries of the east have adopted the in-situ slum up-gradation, the western nations replace slums with high-standard social housing estates (Lin, De Meulder, Cai, Hu, & Lai, 2014). The following sections elaborate on the specific characteristics of the major housing typologies of Mumbai.

4.1. Slums or 'Zopadpattis'

The slums also termed as favelas, ghettos or Zopadpattis (in Mumbai) are characterised by blighted, informal shantytowns for the socially driven class of developing nations' population. Slums, a 'subsystem within a complex system' have been depicted as the 'Kutcha' part within the pucca city or the unintended and undesirable part of a city. Mumbai slums with 52.5% population occupy only 9% of the city's area (Weinstein, 2012). With the one or two-storey units and little public transport provision, Mumbai slums' density results in overcrowding. The externalities worsen with a lack of clean water and sanitation accessibility, flimsy building construction materials and unsafe hygiene advertently leading to the increased risk of communicable diseases and degraded well-being especially among the slum children. However, with site and services scheme and slum up-gradation programmes, the condition of slums in Mumbai has improved since the post-liberalization era.

Dharavi, located in the commercial business district (CBD) of Mumbai, is among the 30 mega-slums of the world and Asia's largest with an area of around 535 acres housing > 1 million people. Here, Ramabainagar, located near Matunga Labour Camp, Dharavi was chosen as the study area (see Fig. 2). The majority of the housing units in Ramabainagar are one-two storeyed measuring to a maximum height of 5 m. Each two-storeyed housing unit consists of kitchen and living zone on the ground level and sleeping area on the upper floor. The single-storeyed tenement units either have integrated kitchen or outdoor cooking facilities. In the case of single-storeyed units, bunk bedding systems are used for storage and sleeping. The living spaces of tenements sharing external walls are ventilated through natural ventilation, with the intermittent operation of a ceiling fan as an air circulation device. The closely packed units can be accessed through narrow one metre wide alleys and are connected to the community-level toilets (Fig. 2).

4.2. Chawls

'Chawls' are manifested as four to five floored buildings with 8 to 16 units per floor. The tenements called 'kholis' are one or two-room units of not > 20 m^2 attached by a common corridor and a central staircase service with shared toilets at each level. Typical 'chawl architecture' is similar to 'Cortico' in Brazil and Portugal and 'Casa di Ringhiera' in Northern Italy. These houses are represented by the long single-loaded corridors with a row of doors on one side and open-to-sky connected balconies on another side, where occupants can socialize. This housing type evolved during the colonial era to house the industrial workers which eventually degenerated into slum-like living conditions (Jana & Sarkar, 2018).

One of the largest cohorts of the chawls was built by the British-era-Bombay Development Department (BDD) in central and south Mumbai. These were chosen as the study area. With 206 buildings, BDD chawls are spread spatially across four regions, namely Worli (120), NM Joshi Marg (32), Sewri (12) and Naigam (42) within the city. A typical building cluster of Worli is depicted in Fig. 2. The buildings are four-storeyed vertical structures of 12 m height. Each floor consists of 20 tenement units of area < 20 m^2, and common toilets at the end of each double-loaded corridor. These houses are located in clusters. These clusters contain 20 buildings, each containing 80 apartments and accommodating at least 1600 households with a population size of 8000. They are juxtaposed along a sequence with 15 m wide inter-building pathways and in-between open spaces.

4.3. Evolution of slum rehabilitation housing (SRH)

While affordable housing policies in India focussed on in-situ slum improvement in early periods (1960–80s), the strategy of house construction and redevelopment gained momentum from the post-1990 era (see Fig. 4, Phase 1: Problem identification). Slum up-gradation schemes were launched to improve the condition of urban slum dwellers by providing improved housing and community toilets. However, the unimpressive outfalls of these policies led to the further promotion of recent housing scheme like 'Housing for All 2022'. During this era, neo-liberalization strategies like public-private partnerships, market interventions were utilised to formalise slums and deliver subsidized beneficiary-led individual housing and basic amenities to low-income families.

Meanwhile, the state-level slum improvement policies in Mumbai have affected the liveability of slum dwellers throughout the years (see Fig. 3). The initial schemes were enforced to eradicate slums from the city through the classical approach of eviction (Bardhan, Sarkar, Jana, & Velaga, 2015). Still, slums have persisted in Mumbai because of slum improvement or up-gradation policies. Moreover, land, being a

Table 1
Review on built-environment parameters and their impact on socio-physical liveability.

Built-environment design variables		Impact on social liveability	Impact on physical liveability
Community-level	Building height difference	• Housing characteristics and structural built have a social gradient. Built form especially building height can deepen concentrated poverty (Badland & Pearce, 2019; Mohit & Iyanda, 2016).	• A neighbourhood with larger differences between the taller and the lower buildings experience better urban ventilation (Ng, 2010). • The amount of indoor wind at the upper floor is four times higher than that for the same room unit in the lower floors of a high-rise tower (Aflaki, Mahyuddin, & Manteghi, 2014). • Building height differences improve ventilation and enable better pollution transport rate, thereby improving the physical liveability (An, Wong, & Fung, 2019; Clements-croome et al., 2017).
	Side alleys/canyon ratio/H/W ratio (height of the building: width of adjacent streets)	• A significant 'design component' of liveable commercial streets (Mazin & Radi, 2019). • A major measure of sustainable neighbourhood liveability (Norouzian-maleki, Bell, Hosseini, & Faizi, 2018). • The most preferred canyon ratios were 1:1 and 1:1.5, whereas the least preferred canyon ratios were 1:2.5 or 1:3 (Norouzian-maleki et al., 2018).	• Parametric studies of wind flow in street canyons suggest H/W ratio of 2 or less. With higher H/W ratio the ventilation deteriorates as wind vortexes tend to form at lower sections of buildings, thus weakening the ground-level wind (Ng, 2010). • Walkable areas in disadvantaged zones have higher pollution and traffic exposure, leading to reduced social cohesion and degrading physical health (Badland & Pearce, 2019).
	Open spaces	• Public greenery or vegetation, amount or presence of open spaces or space enclosed by building blocks is an efficacious factor for measuring urban/built-environment liveability (Hooper, Boru, Beesley, Badland, & Giles-corti, 2018; Hooper, Knuiman, Foster, & Giles-corti, 2015; Southworth, 2019). • 20–40% of public and private greenery would improve the residential liveability (Norouzian-maleki et al., 2018). • Public-parkland at different scales and per cent houses within 400 m of any park were measured as a safety parameter for neighbourhood liveability (Foster, Hooper, Knuiman, Bull, & Giles-corti, 2016). • 'Open or social space' or 'social interaction space' was linked with the sociological construct of residential liveability (Bardhan et al., 2018; Skalicky & Čerpes, 2019). • Inequality was observed in the provision of green spaces in disadvantaged areas, which affect the health and liveability at large (Badland & Pearce, 2019). • Neighbourhoods with higher socioeconomic status have higher accessibility to urban green spaces (Sathyakumar, Ramsankaran, & Bardhan, 2019).	• Open spaces can significantly enhance urban ventilation, through the creation of air channelling paths (Ng, 2010). • Urban green spaces have a strong correlation with urban built density (Chan & Liu, 2018; Sathyakumar et al., 2019). • Urban morphology (Ramponi & Blocken, 2012) and building arrangements (An et al., 2019; Cheung & Liu, 2011; Zhang, Gao, & Zhang, 2005) have impact on pollution dispersion and ventilation levels, major indicators of physical liveability, health and well-being (Badland & Pearce, 2019; Clements-croome et al., 2017; Mazin & Radi, 2019). • 8% of active open space is essential for better health outcomes (Hooper et al., 2018).
Building level	Internal corridor/interior alleys	• Building corridors act as communal spaces for women, working spaces for small-scale household industries, and play areas for children in the rehabilitation colonies of Mumbai (Sunikka-blank, Bardhan, & Nasra, 2019).	• Improved corridor design and ventilation would promote better indoor environment, thus indirectly impacting the physical liveability (Zhou et al., 2014).
Interior level	Kitchen/toilet/bedroom size and location	• Interior partition-walls, aiding in improving the privacy quotient, acts as a socio-architectural parameter affecting social liveability (Sesotya, Arifianto, & Nadiroh, 2017).	• Partition-walls involve improvement in the indoor environment, ventilation rates, airflow, pollution transport rates (Huo, 1997; Lee & Awbi, 1995). • Multipurpose tenements with unsegregated kitchen-living spaces have degraded indoor air quality (Lueker, Bardhan, Sarkar, & Norford, 2020). • Residential space-separators segregating kitchen and living zones, optimum ventilator, cook stove and bed location (Sarkar & Bardhan, 2019b) reduce the temperature in living areas, thus reducing energy consumption and improving thermal comfort levels (Aryal & Leephakpreeda, 2015).

premium in Mumbai (Jana, Bardhan, Sarkar, & Kumar, 2016), presently, 95% of Mumbai population cannot afford to buy a house in formal sector (Gandhi, 2012). Therefore, later 'Special Township Policy', 'Cluster Development', 'Inclusive housing in layouts', 'Slum Rehabilitation Scheme' etc. were initiated. Here a certain percentage of the new built-up area was reserved for Lower Income Group (LIG). Among all these programmes, Slum Rehabilitation Scheme (SRS) in 1995, turned momentous in Mumbai.

Initiated by the Maharashtra State Government and Mumbai-centred Slum Rehabilitation Agency (SRA), the goal of the scheme was not only to legalize and protect slums from eviction but to provide them improved housing through resettlement (Jana et al., 2016). While the slum dwellers were benefitted with legal tenure and better housing free of cost, the private developers were incentivised to build 'sales component' for the high-income population from the project. However, the key control over land remained with the state government (Nijman, 2008).

It can be argued that despite facing condemnation globally (Muchadenyika & Waiswa, 2018), the slum rehabilitation approach indeed constituted an improvement in Mumbai in last two decades. Till October 2014, around 20,121 housing units were completed by MHADA; 1, 57,402 housing units were completed by Slum Rehabilitation Authority (SRA), and 26, 101 housing units were constructed by Mumbai Metropolitan Region Development Authority (MMRDA (SRA cell)) in Mumbai (Ford Foundation & Madhu Mehta Foundation, 2014). Thus the Slum Rehabilitation Houses (SRH) are recent addition in the

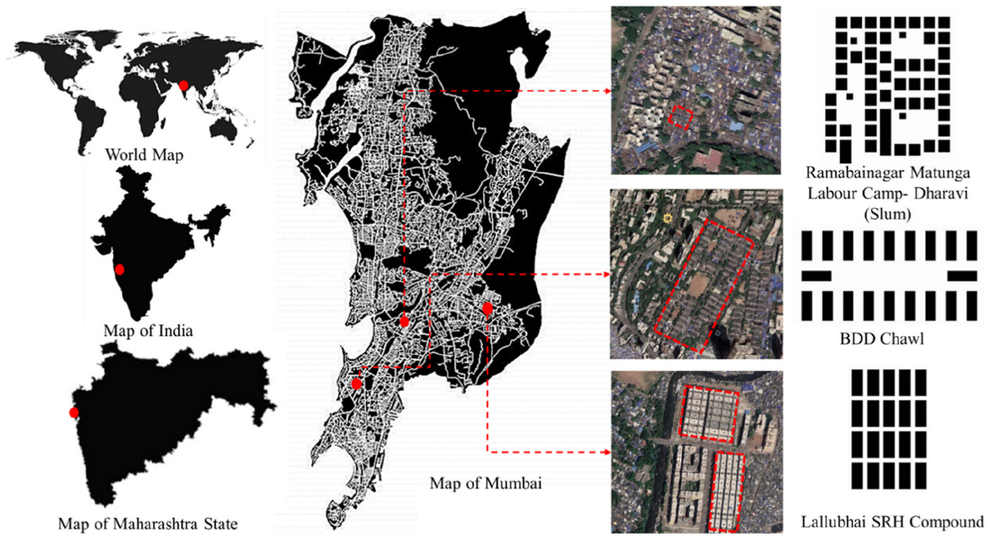


Fig. 2. Regional context and built-environment characteristic of archetypes of informality.

landscape of Mumbai.

The recent SRHs are characterised by densely packed multi-rise towers with low intra-building spaces. SRH buildings are typically tall ranging from 5 to 30 floors with apartment units < 25 m^2. The housing complexes are gated communities where inhabitants enjoy land security and tenure. The buildings are equipped with elevators, common central staircase and shops at ground level. Through the successful rehabilitation process, the slum dwellers are benefitted with provision to individual-level basic infrastructure, land tenure, access to the capital in the form of property. Yet they often end up in forfeiting the small-scale economic opportunities and a certain freedom to develop their own habitat.

The SRH named Lallubhai compound constructed in 2003 in Markund, Mumbai, was chosen as the case study area (see Fig. 2). Lallubhai compound, a typical manifestation of slum rehabilitated low-income multi-rise apartments consists of 65 towers. The vertical towers have eight floors 25 m high. The SRH housing units, placed alongside a two-metre wide double-loaded corridor are one-room apartments of 21.42 m^2 area, with attached individual level bath and toilet (2.47 m^2) and an unsegregated kitchen-living space. Each floor hosts 13 tenements, with a total occupancy of 104 tenements per building. Here, the study area consists of a portion of the SRH colony, with 20 such apartments, which accommodates 2080 tenements with an approximate population of 10,400. These 20 buildings are stacked one after another with an intra-building space of 3 m.

However, these low-income multi-storeyed slum rehabilitated towers, a ubiquitous symbol of modernism is now manifested as mechanised habitats. These towers through technological protocols discursively audit space by absorbing more people vertically. However, in this process, the socio-cultural needs of the low-income society remain unrecognised leading to disruption of long-term sustainability, ultimately forcing the residents to shift to slums.

Survey-based studies by Bhide et al. (2003); Restrepo (2010) discloses "*incompatible living space*" with deteriorated liveability and "*unaffordable livelihood*" as the two principal causes of shifting to other slums from SRHs. Slum-dwellers chose to stay back in slums owing to accessibility challenges- as formal housing with higher costs of maintenance imposed durability issues for those, who were unable to support the cost of living of it. Another personal interview and focus-group-discussion (FGD) based narrative study in three SRHs of Mumbai elucidated that the major reasons behind rebound phenomenon include "*increased cost of living, poor income, no childcare, no usable outdoor and*

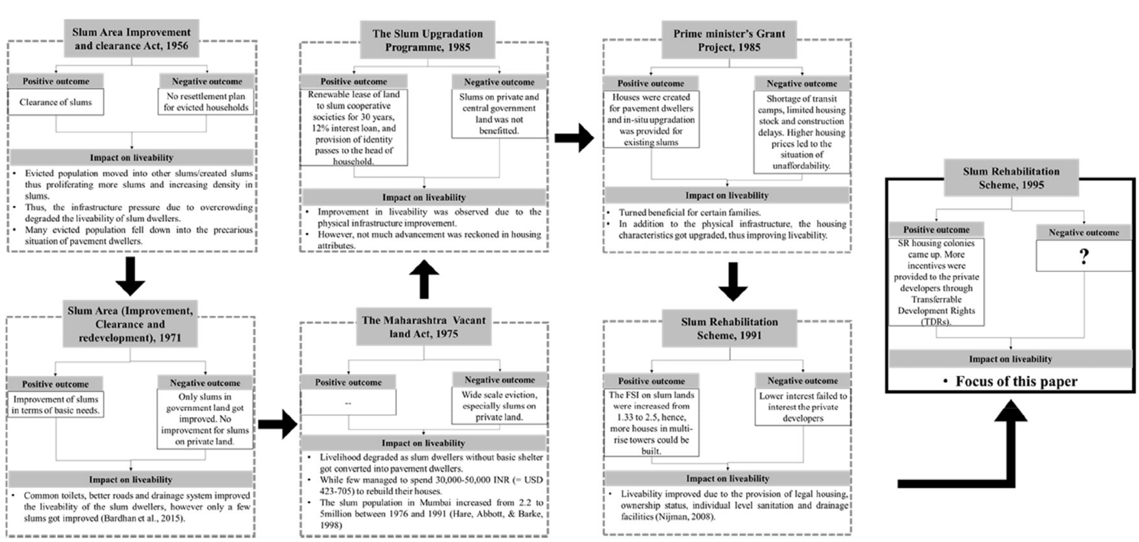


Fig. 3. The critic on slum improvement policies and how their effect on the residential liveability.
Adapted from Bardhan et al. (2015).

lack of social interaction space" (Sunikka-blank et al., 2019). Debnath et al. (2019) also pointed out that while nearly 70% of the slum (Dharavi) households perceived 'a feeling of community', social isolation emerging from socio-architectural attributes "*like lack of safety daylight, and ventilation availability in the corridors and in-between buildings*" made them think of shifting to horizontal slums. The reason for leaving the formal housing and creating another slum could be economic also since the rent they would get from these apartments would help them to run their families.

The major conceptual shortcomings behind this phenomenon include i) the ineffectiveness in integrating modern planning and design interventions to existing development patterns and, ii) paucity of predisposition towards the people-centric spatial development. Echanove and Srivastava (2011) contended that the trade-off between the high-rise (with land tenure, better infrastructure and living status) and low-rise (with economic opportunities, social networks, subsistence and freedom to develop own habitat) is generated by the lacuna in planning regulations. This incongruity would end up in producing urban forms that have already failed in Chicago and Paris, where solely engineered solutions were provided to solve housing crises. A more grounded understanding of parameters contributing to the loss of socio-physical liveability of the SR residents is necessary.

5. Research methodology

A mixed methodology is adopted for evaluating socio-physical liveability in the present low-income housing with socio-architectural complexities. Based on a sequential heuristic, this study forwards a systematic process-oriented assessment approach drawn upon Mumbai SRH as a prototype of low-income housing architecture (see Fig. 4). The methodology pursues to investigate the built-environment design that contributes to the problems currently faced by the slum rehabilitants. The overall framework toes on the association of built-environment and socio-physical liveability. The study is executed in five phases.

Phase 1: Investigating the current challenges in low-income housing: a policy analysis.
Phase 2: Highlighting the reasons behind the challenges in low-income housing by reviewing global scenarios and theoretical assumptions.
Phase 3. Identification of indicators of built-environment and socio-physical liveability through literature study.
Phase 4. Selection of spatial solutions and measure/simulate the interaction between built-environment and socio-physical liveability.
Phase 5: Analysing the association between the built-environment and socio-physical liveability through the case-study application.

This method was designed on three tracks, first assessing the resettlement policy impacts; second is reviewing the current built-environment attributes of SRHs with respect to the social and physical liveability measures, and the third is the built-environment design-related feasible recommendations. To assess the efficacy of the present low-income housing in Mumbai, the national and state-level slum improvement policies were initially explored with a focus on their impact on liveability on the low-income sector. Transect walks, local interviews and the reconnaissance surveys were conducted in the low-income archetypes to understand the built-environment attributes, household behaviour and practices.

A critical analysis of the social liveability of the existing SRH typology was undertaken in comparison to that of the slums and chawls. The socio-physical aspect of liveability was assessed using the indicators of built-environment. The importance of built-environment indicators in modifying the socio-cultural liveability was established through the comparative investigation.

It is well-acknowledged in the literature that effective natural ventilation strategies can comprehensively impact comfort in built-environment. Natural ventilation driven site-based air movement apart from improving indoor air quality, and thermal comfort also reduces health cost up to 18% (Dutton, Banks, Burnswick, & Fisk, 2013)), thus improving the physical liveability of the residents (Badland & Pearce, 2019; Clements-croome et al., 2017; Mazin & Radi, 2019). Hence, natural ventilation potential through site-based airflow distribution was considered as a surrogate measure of physical liveability. Wind-related data was collected from the Indian Meteorological Department (IMD), Mumbai as well as through in-situ environmental sensor deployment. The site-based airflow patterns and ventilation potential of the present SRH layout was compared with i) slum and, ii) chawl using Computational Fluid Dynamics (CFD) simulations in ANSYS Fluent software. Finally, the indicators of built-environment were utilised to generate hypothetical iterated scenarios, followed by the testing of the socio-cultural and physical liveability.

It can be reasonably expected that the assessment of the proposed built-environment for the comparative investigation of socio-physical liveability in three different archetypes of low-income housing would demonstrate the difference in liveability quotient.

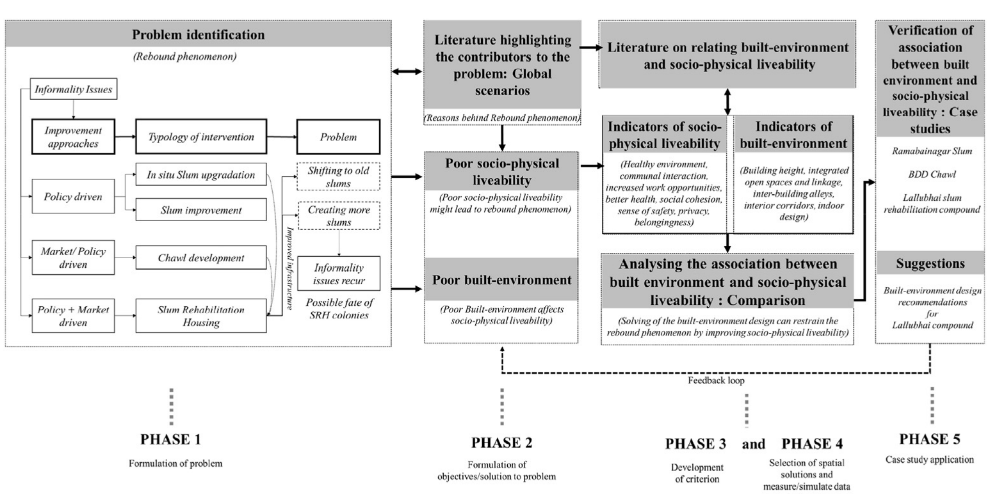


Fig. 4. Methodology adopted in this study.

Fig. 5. Built-environment design parameters in different archetypes of the informality of Mumbai.

6. Analysing social and physical liveability through socio-spatiality

6.1. Analysing social liveability

As argued by Roy (2009) 'materiality of informality' or slum (Kovacic, 2018) demonstrates its physical aesthetic aspect, which currently ends up in exhibiting places of physical and social degradation. Housing crisis solution in Mumbai has invited mere technical management of slums, particularly focussing on techno-fixes of poverty through shallow materialistic upgradation. Nevertheless, this less-sensitive approach of compressing into towers has significant knock-off effects on the social well-being.

The compactly arranged 'pigeon-hole' like tenements piled in a vertical frame has pushed the inhabitants of Lallubhai compound indoors, thus segregating them from community interactions (see Fig. 5). A semi-private open space along with children play area within the proximity of homes enable inhabitants particularly women to socialize with their neighbours while monitoring on household activities (Sunikka-blank et al., 2019). These spaces imbibing the sense of communal coherency are prevalent in Ramabainagar and even BDD chawls. This is because of the relatively lower height structures, which connect the inhabitants to the adjacent outdoor space as observed in few national low-cost housing like CBD Belapur incremental housing in Navi Mumbai designed by architect Charles Correa and Aranya low-cost housing in Indore designed by architect Balkrishna Doshi.

In Ramabainagar, for example, the majority of the low-rise structures adjacent to public streets extend as living quarters, areas of small-scale manufacturing and sale, and mostly, places of community gathering. However, this social coherency and visual cognitive connection get disappeared in the non-permeable high-rise SRH developments. This concept of 'Shanghaiazation of Mumbai' through inevitable high-rise development absorbing more people on a smaller footprint of land, was heavily criticized by architect Charles Correa in 'The New

Landscape' (Correa, 1988). The solution of vertical development of low-cost housing thus turns into a deceptive affair in the name of 'status' due to weaker ecological and economic framework of the city (Echanove & Srivastava, 2011).

Ramabainagar slum, in the lieu of space-constraints, has grown chaotically over the years. However, the side or back alleys are maximum utilised as secondary pedestrian paths and service lines. Owing to the high human interaction within these pathways, the slum dwellers maintain these narrow but effective alleys with a sense of belongingness and responsibility. Hence, the one-metre wide intra-building side alleys turned into positive community spaces.

Similar phenomenon is noticed in the BDD chawls, where the side and back alleys are enough wide (15 m wide) and are often utilised as informal market places and vehicle parking areas. Consequently, these spaces enhance human interaction and social networking thus increasing the vibrancy and vitality of the space. The number of social connections is higher in courtyard shaped 'chawls' than that of modern typical apartment building configuration. Karandikar (2010) demonstrated through 'the chawl-to-flat trauma' and interviews that despite chawl-to-flat movement would eradicate the sense of poverty, it would also deteriorate the social cohesiveness. On similar lines, Alexandra Curley had demonstrated that '*social networks often play an important role in the development of people in life and that their neighbourhoods of residence can shape these networks*' (M. Curley, 2010). In 'A Pattern Language: Town-Buildings-Construction', Christopher Alexander demonstrated how building layouts can be rationally designed and configured to create successful social interaction places (Alexander, 1977). The built-environment design of Mumbai 'chawls', despite pushing the inhabitants into cramped spaces, offer them a strong sense of community coherence, safety and better social well-being (Karandikar, 2010). Hence, recent state government initiatives to transit the 'chawl' dwellers to skyscrapers have left them with a tough choice between a better standard of life with increased privacy and sense of kinship.

On contrary, the over cramped side alleys in Lallubhai SRH with poorly maintained service trails inhibits human accessibility. While General Development Control Regulation (GDCR), Mumbai (Mumbai DCR, 2016) (GDCR) and National Building Code (NBC) prescribe intra-building distance to be one-third of building height, the Slum Rehabilitation Development Control Regulation (DCR) Section 33(10) guidelines have relaxed it to a maximum of 6 m for buildings' height up to 32 m (Slum Rehabilitation Authority, 2017). Though the evolving policies advise high-rise towers for SRHs, the intra-building spaces remain constant.

The narrow alleys between the extreme vertical adjacent towers, instead of exhibiting adjoining community zones, results in the formation of 'negative' (Azhar & Gjerde, 2016; Carmona, 2010), disconnected and 'non-community' spaces (Lee, Hwang, & Lee, 2015) which often serve as catalysts of crime (Bardhan et al., 2018). These spaces eventually converted into public refuse or waste-yards, reduce the social concern towards space and highlights social vulnerability by degrading the interaction between territoriality and surveillance opportunities. Also, the poor environmental conditions within these alleys refrain the Lallubhai inhabitants from opening windows, which further deteriorated the social coherency. Therefore, it can be argued that although residents got benefitted from standard quality infrastructures and housing structures, the SRH towers seized their subsistence, which is a subject of their close proximity to the adjacent streets.

A broader impact of poor building design is rupturing of the vicious cycle of time, economic and social poverty which has impeded the occupants from entering formal labour market directly or indirectly (Bardhan et al., 2019; Sunikka-blank et al., 2019). Thus, specific physical designs of current slum rehabilitation not only challenge the theories of 'Defensible Space' and 'Broken Window', but also the argument offered by Jane Jacobs that '*buildings should be positioned to provide natural surveillance of the street*' (Jacobs, 1961).

Another major concern is the interior layout which also epitomises the social setting and shapes occupant behaviour. The evolutionary process of slum up-gradation has witnessed marginal growth in interior design development. It can be argued that different stake-holder intervention in the slum rehabilitation process has focussed only on external service overlooking the internal housing quality, the convenience of inhabitants and their living pattern. The housing units of Ramabainagar, gradually built by the occupants themselves have considered the notion of physical privacy by segregating the kitchen, living and sleeping zones in different levels. But, the BDD chawls and the Lallubhai SRH compound developed by the government and private agencies, have focussed on occupancy maximisation, by delivering each five-to-seven membered family a single multi-purpose kitchen-living space of < 20 and 25m^2 respectively. The modifications in design parameters throughout the evolutionary process of SR specialised DCR included an increase of tenement unit size from 20.9 m^2 (1995) to 25 m^2 (2016) on one hand and increase of density from 500DU/Ha (1995) to 650DU/Ha (2016) on the other hand, thus stressing occupancy maximisation. The current density of SRHs is as high as 1300 DU/Ha (Bardhan et al., 2018). Thus, the problems of overcrowding and lack of privacy remain unresolved in the slum rehabilitation units.

The above arguments demonstrate that the material upgrading policies imbibed within SR policies have introduced significant modifications. Yet, further nuanced approach is required in terms of the built-environment design and housing quality, with consideration of the contextual social-setting as a governing policy variable.

6.2. Analysing physical liveability

The site-based airflow analysis around the buildings with an ambient air velocity of 2.5 m/s is illustrated in Fig. 6. The 'dark blue' bands infer that natural ventilation is insufficient to promote thermal comfort in the living spaces through cross-ventilation. While the 'green' to 'red' bands infer that naturally-driven wind velocity would be able to deliver thermal comfort and high air exchange rates without the aid of any electro-mechanical devices (Bardhan et al., 2018).

The housing units in Ramabainagar slum with building heights ranging from one to two floors maintain a heterogeneous urban fabric. This differential building height, by inducing positive and negative pressure on both sides of buildings, increases the site-based ventilation (see Fig. 6A). The one-metre wide side alleys with adjacent one-floor high building mass generate shallow street canyon (Height is to width i.e. H/W ratio = 2.5), enabling the formation of wind vortexes, which in turn effectuate ventilation (0.52–1.14 m/s).

The BDD chawls, stacked along one another exhibit enhanced air ventilation owing to well acceptable H/W ratio of 0.8 (Fig. 6B). Subjective interpretation of these layouts reveals that the presence of the integrated open space and adequate inter-building spaces within the building composition enhances the overall average site-based airflow (0.72–1.5 m/s) (Bardhan et al., 2018).

The poor airflow characteristics of Lallubhai SRH colony, as shown in Fig. 6C is majorly due to the compactly arranged tall and bulky buildings with minimum intra-building spaces. A simulation-based study conducted in Hong Kong by Yuan and Ng (2012) had suggested that densely spaced buildings increase the wind resistance and obstruct the airflow in the neighbourhood. The tight, narrow streets in Lallubhai SRH compound and with tall structures on both sides result in the formation of deep urban canyon with H/W ratio of 8.33, substantially higher than the prescribed value of 0.7 as per Oke's theory (Ng, 2010). A study by Al-Sallal and Al-Rais (2012) suggested that despite deep street canyons provide favourable temperature in summer months, shallow canyons improve building ventilation levels. Next, for the air paths to be effective, height and length of the buildings should be three and ten times the width respectively (Ng, 2010). But, Lallubhai SRH building had length, width and height of 60 m, 30 m and 25 m respectively which heedfully blocked the air path. The Team Clean Final Report of Hong Kong recommended that lack of breezeways networks,

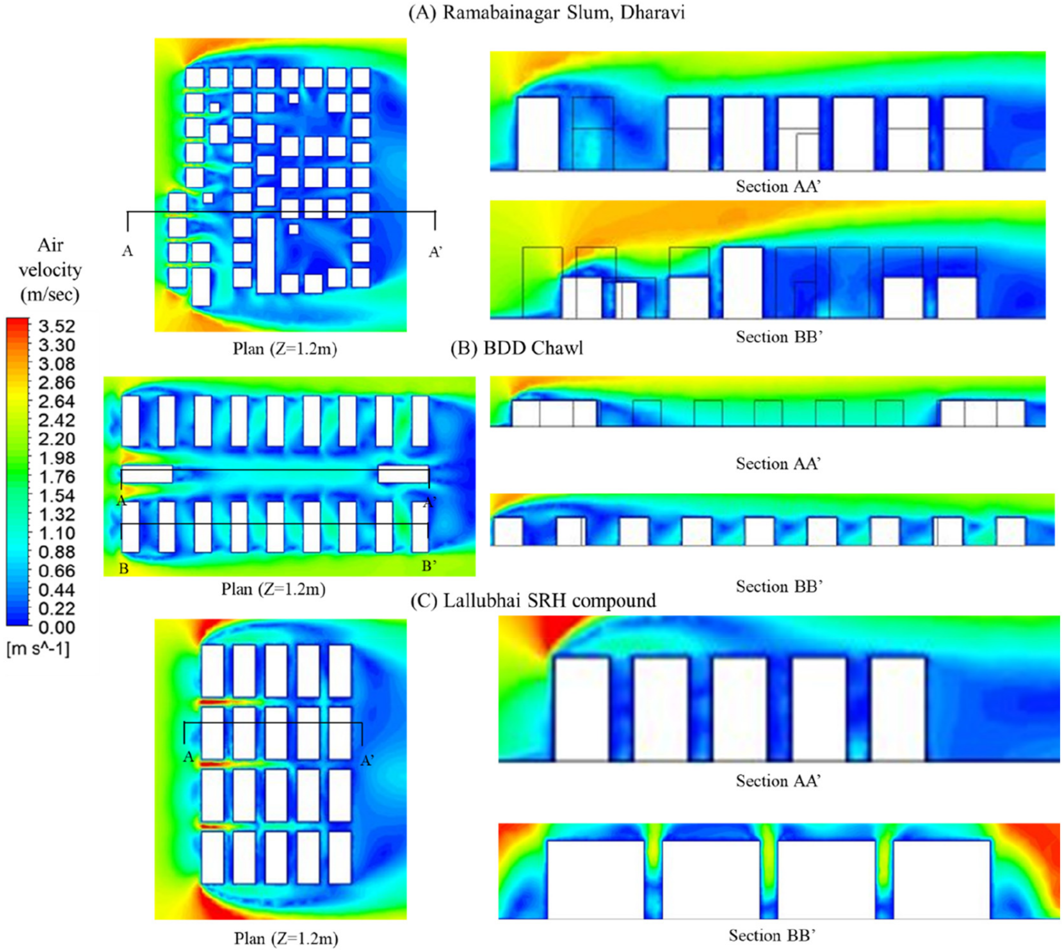


Fig. 6. Airflow simulations of existing layouts in (A) Ramabainagar Slum, (B) BDD chawl and (C) Lallubhai SRH compound.
Note: The airflow simulations were carried using computational fluid dynamics in ANSYS Fluent with ambient air velocity = 2.5 m/s, RANS steady-state K-Ɛ turbulence model.
(Airflow data collected from Indian Meteorological Department Mumbai).

Table 2
Performance of environmental metrics for different archetypes of informal settlements.

Environmental metrics	UBF 3 (medium–rise MHADA colony/ BDD chawl)	UBF 4 (high-rise slum rehabilitated housing)	UBF 5 (low-rise slums)	Reference
T_{mrt} (thermal)	High	High	Low	Mehrotra et al., 2019
C_p (thermal)	Low	High	High	
H_x (thermal)	Low	High	High	
HSRI (thermal)	Low	High	Medium	
Air velocity (from the simulations conducted in this study)	High (0.72–1.5 m/s)	Low (0.5–0.98 m/s)	Medium (0.5–1.14 m/s)	Author's computation

densely packed tall and bulky buildings, uniform building heights, tight and narrow alleys, lack of urban permeability and insufficient air spaces deteriorated the urban ventilation which in turn resulted in poor ventilation, thermal discomfort and break-out of Severe Acute Respiratory Syndrome (SARS) in Hong Kong in 2003 (Team Clean Report, 2003). In SRH colonies like Lallubhai compound, the buildings with similar height, and devoid of any intermediate open spaces reduce the overall site-based airflow performance and degrade air exchange rates. The results also commensurate with another study of Mumbai (see Table 2), where the urban built form (UBF) of SRH colonies exhibited uncomfortable thermal environment for maximum time of the day, highlighting thermal distress (Mehrotra, Bardhan, & Ramamritham, 2019). The study also demonstrated that the urban built form typology of MHADA colony/BDD chawl performed best in terms of thermal indices like Mean Radiant temperature (T_{mrt}), Cooling potential (C_p), Humidity index (H_x), and Heat stress reduction index (HSRI).

In addition to this study, Table 2 also points out that among the three archetypes of low-income housing, the BDD chawls performed best in terms of simulation predicted air ventilation performance with Lallubhai compound ranking least with an average air velocity of 0.5–0.98 m/s. Additionally, household air pollution (HAP) from closed windows situation and cooking in unsegregated kitchen promote inferior indoor air quality (IAQ) in SR housings. Experimental researches in the SR buildings identified that indoor air exchange rates (ACH: air change per hour), a well-established proxy measure of ventilation rate is four times lower when windows were closed and ceiling fans were functioning, in comparison to the scenario when just windows were kept opened keeping ceiling fans switched off (Lueker et al., 2020). This

Table 3
Built-environment parameters of SRH compounds in comparison to slums and 'chawls'.

Built-parameters	Improvement	Reason	Observations in SRA	Implications
Height of building	No	More people have been accommodated	Tall and bulky structures without adequate intra-building spaces	Physical: • Lack of efficient airflow, disruption of air path and breezeways. Social: • Lack of sense of safety and increased social seclusion
Open space	No	Community open spaces absent	No community-level space, play areas	Physical: • Lack of site-based airflow Social: • Lack of social cohesiveness, communal gathering
Side alleys	No	Degraded ventilation within alleys (acceptable H/W)	Extremely narrow (H/W: >8) leading to the formation of waste-yards	Physical: • Foul smell from waste-yards force occupants to close windows which degrade IAQ. • These waste-yards form breeding grounds for insects, deteriorating health of occupants. Social: • Lack of community control over the spaces, • Increase of vandalism and crimes in those alleys, • Lack of cognitive and visual connectivity
Kitchen	No	Kitchen within slums either outdoor or at lower levels	Pollutant and smoke persist in living areas due to unsegregated kitchen	Physical: • Poor IAQ in the kitchen as well as living rooms Social: • Women health, well-being and liveability get degraded.
Toilet	Yes	No individual toilets in slums and chawls	Attached toilets (but often not maintained)	Physical: • Breeding of germs from uncleanliness and lack of maintenance leading to health and hygiene issues
Living area and bedroom	No	2 floors in slums segregating kitchen and living zones	Space constraint	Physical: • High temperature and pollutant concentration due to unsegregated kitchen • Low air exchange rates Social: • Overcrowding • Lack of privacy
Interior corridor	No	Ventilators in slums opening to alleys	No ventilation	Physical: • Lack of airflow and daylight within the corridors Social: • Degrades community interaction

emphasises the argument that ceiling fan simply serves as an air circulation device and does not aid in improving ventilation quality. Ventilation effectiveness can either be accomplished by utilising natural ventilation potential through opened windows or through mechanical ventilation strategies like an air-conditioner. The phenomenon of the opening of windows becomes exigent in low-income settlements, owing to their economic constraints which refrain them from adopting electro-mechanical ventilation modes. Sunikka-blank et al. (2019) also portrayed that inhabitants within Dharavi slums prevailed better IAQ as the women after cooking activities tend to spend their time in adjacent integrated open spaces. But in SRH colonies, women spend whole time indoor, thus being highly exposed to indoor smoke and pollution from cooking. Hence, better built-environment design considerations with effective cross-ventilation strategies become crucial in slum rehabilitations. Table 3 explains the modifications in SRH built-environment over traditional slums and their respective implications on social and physical liveability.

From the above socio-physical liveability assessment, it can be argued that this challenge of 'rebound phenomenon' can fairly be alleviated by incorporating intelligent and inclusive built-environment design, which currently remains the least priority in low-cost housing. This would assist in producing viable built-environment design alternatives to the perpetual loop of demolition and reconstruction that impede sustainable urbanization.

7. Discussion

Global research steered towards design improvement strategies for slum redevelopment projects have predominantly identified the inclusion of critical viewpoint of slum-dweller in the design stage. Hence, new approaches suchlike sky-villages in Singapore, and self-directed development in Chile, have come up as a culturally sustainable alternative (Hindman et al., 2015).

Based on the context and theoretical assumptions, the authors proposed a hypothesis: *Modification of built-environment indicators can restrain the rebound phenomenon by improving the liveability of SRH residents through the promotion of enhanced environment*. And it is the validity of this hypothesis that was comprehensively tested in this section.

This section focused on the built-environment indicators which when modified based on literature and environmental simulations, would improve the physical and social well-being of the inhabitants. Here, the housing layout of Lallubhai SRH compound was parametrically examined by individually varying socio-architectural and geometric indicators that impact socio-physical liveability. This investigation was coupled with CFD-based site-based and interior airflow analysis to investigate the suitability of a housing layout under socio-technical challenges. Here, it is theorized that 'improved physical liveability including occupant comfort and health can be achieved by ensuring better ventilation, which is a function of built-environment design'. Also, the hypothesis continues by assuming that 'the same built-environment design would also increase the social liveability of SRH inhabitants.' If this hypothesis turns true, this needs to be incorporated in the bye-laws for re/construction of low-income housing in cities of developing nations especially in the global south.

7.1. Recommendations

Results from CFD predicted air-movement analysis of the iterated hypothetical scenarios explained that the incorporation of the built-environment design parameters modified the socio-physical liveability.

7.1.1. Exterior level built-environment design parameters

Building Height Difference: While the existing building layout consisted of 20 buildings with similar height, the hypothetical scenario consisted of a heterogeneous concoction of six, seven and ten floored buildings. However, in this case, the other built-environment indicators like the number of dwelling units, intra-building space, building shape and site area were maintained same as the existing scenario. The simulated layouts exhibited that while in existing scenario the inter-building airflow remained low i.e. 0.22 m/s, the airflow characteristics modified significantly with the building height differentials. Table 4 demonstrates that the taller structures tend to trap the wind and downwash it to the lower zones. This downward effect happening on the windward and leeward facades via spiralling vortexes induced positive and negative pressures on the two sides of the building. Thus, the simulated average air velocity on the windward and leeward façades was observed to be 1.54 m/s and 0.88 m/s respectively, considerably higher than the existing scenario.

Open space: Mehrotra et al. (2019) concluded that SRH built-form if would undergo structural modulation by reducing built-area, would allow better airflow which in turn would improve the thermal environment. The existing scenario of a continuous sequential array of buildings was modified in the hypothetical case by integrating open spaces into the housing layout. Five building blocks were removed for creating integrated open areas. Yet, the number of floors of all existing blocks (initially eight floors) were adjusted to 12 floors to accommodate the removed ones, thus maintaining the number of dwelling units and site area same. The open spaces and their linkages served as a way to form breezeways or ventilation corridors. These uninterrupted air paths (in case of the hypothetical case) through non-building areas improved ventilation with intra-building air velocity ranging between 1.32 and 2.22 m/s. Moreover, the open spaces would act as social interaction spaces as well.

Intra-building spaces/side alleys: In our study, the intra-building spaces were increased from 3 m (existing case) to 12 m (hypothetical case), while maintaining the other parameters like building height and disposition same. Consequently, the plot area got increased however decreasing the density by 136DU/ha. It was observed that the higher intra-building distances aided in better airflow within the windward facades by creating shallower street canyon (i.e. H/W ratio from 8.33 to 2.03). The increased intra-building alleys also create positive 'defensible spaces' within the housing community, thus decreasing social vulnerability. These alleys also create spaces for informal markets.

7.1.2. Building level built-environment design parameters

Internal corridor: The high-rise SRH building of Lallubhai compound is characterised by rectangular structures with a double-loaded corridor, which fails to facilitate the flow of outside air into the interior zone. As a rectification strategy, one air-path in the north-south direction and two air-paths in the east-west direction were designed by introducing openings on the two ends of corridors and beside the stair-wells. Furthermore, the staggering of the tenement units' position increased the turbulence in the wind path within the corridor. The wind-direction was considered normal to opening with an average sensor-recorded wind speed of 0.98 m/s at the inlets (here openings). In the existing scenario with a straight corridor, no openings and non-staggered tenement units, the internal corridor barely received any ventilation. While, for the hypothetical scenario, the predicted air velocity ranged between 0.12 and 0.64 m/s with higher velocities near the outlets and tenement units. The varying corridor space could also act as a social-interaction area where women can socialize, children can play, thus increasing social coherency and communal networking.

7.1.3. Interior level built-environment design parameters

Partition wall, ventilator position: The existing tenement unit of Lallubhai SRH colony, with a multi-purpose unit and unsegregated kitchen space perform poor in terms of social liveability parameters like privacy and physical well-being parameters like IAQ and ventilation (Sarkar & Bardhan, 2019a). Hence, a hypothetical interior design layout was generated by introducing a partition wall which would serve the purpose of space-separator (Sarkar & Bardhan, 2018, 2019b), and a high-level air outlet (ventilator: 0.3mx0.3 m) for effective cross-ventilation (Priyadarsini, Cheong, & Wong, 2004). While the sensor measured indoor air velocity over the breathing zone of existing tenement unit was 0.13 m/s, the CFD predicted indoor air velocity in the living area of the hypothetical unit was 0.7 m/s, well within the comfort threshold when outdoor wind velocity recorded at window level was measured 0.98 m/s. The addition of partition wall and ventilator not only improved indoor air velocity profile but also maintained the indoor privacy quotient (Sesotya et al., 2017).

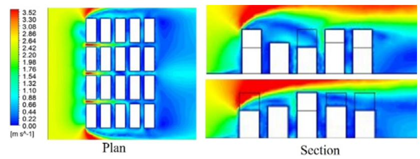
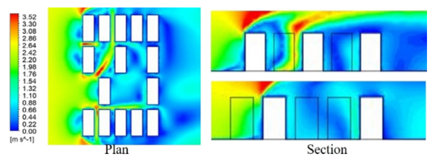
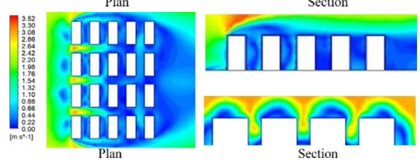
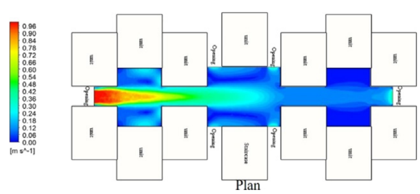
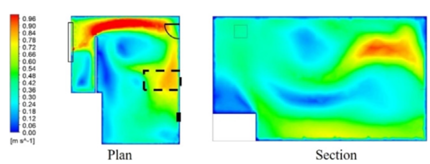
Hence, it can be argued from the established literature as well as the environmental simulations that appropriate building disposition, variated building heights, open spaces and their linkages, and shallow street canyons at exterior level, corridor design at the building level and unit design layout at interior level improve ventilation in SRH colonies. The afore-analysed built-environment design parameters also modify the social liveability by increasing visual cognitive connection, community interaction, social networking and privacy levels. Better built-environment designs also increase the prosperity of small-scale informal activities thus increasing livelihood generation opportunities within low-income communities.

8. Conclusion

This study established the significance of 'loss of socio-physical liveability' as a key-aspect of the impoverishment of involuntary slum displaced population in addition to several factors proposed by IRR theoretical model. Through a substantial literature and a case study in Mumbai, this study also established that 'socio-spatiality' has a strong and reliable relationship with socio-physical liveability of the slum residents. Assessment of the case-study of slum rehabilitation in Mumbai in comparison with other archetypes of low-income settlements validated that 'built-environment', a major aspect of the 'socio-spatiality', with rational modification can improve the socio-spatial quotient and might bring the slum rehabilitants out from impoverishment by improving their socio-physical liveability. The study was developed using an additional key-aspect of 'socio-physical liveability' and its interlinkage with built-environment indicators required for evaluation of liveability of the displaced population.

The set of built-environment indicators of building height

Table 4
Recommendatory built-environment design parameters.

Indicators	Literature	Specification	CFD simulations of hypothetical scenarios	Recommendations and implications
Height of buildings	(Ng, 2010)	Existing scenario: 20 blocks (G + 7) Hypothetical • 8 blocks (Ground + 9) • 8 blocks (Ground + 6) 4 blocks (Ground + 5)		Differential heights within housing compound increase air ventilation turbulence over the urban fabric, particularly on windward facades of buildings.
Open space	(Bardhan et al., 2018)	Existing scenario: No open space Hypothetical 5 buildings removed to create open space		Community spaces/play areas within 6–8 buildings promote adequate ventilation. Development plots should be laid out and oriented by introducing non-building areas. Increases social interaction.
Side alleys	(Shishegar, 2013)	Existing scenario: • 3 m H/W ratio: 25/6 = 8.33 Hypothetical: • 12 m H/W ratio: 25/12 = 2.08		Increased side alleys width shallow street canyon should be provided so that air can reach inner parts of urbanized areas particularly at lower floors of high-rises. Increases safety, and reduces community vulnerability.
Interior alleys	(Zhou et al., 2014)	Existing scenario: • No opening in corridor Hypothetical: Openings at end of corridor and beside the stair-well		Staggered placement of tenement units increases the obstructions in the air path creating turbulence and distributes high-velocity zones near the tenement units and outlets. Increased cross ventilation in corridor increases ventilation within tenement units through a ventilator. Increases the possibility of higher social interaction level in corridors.
Kitchen + toilet + living and bed room	(Lee & Awbi, 1999)	Existing scenario: • Unsegregated kitchen, No cross-ventilation when door remains closed Hypothetical: • Segregated kitchen • Ventilator added		The partition wall between kitchen and bedroom, installed exhaust fans or ventilator in kitchen area dispose of polluted air better.

differential, integrated open spaces and greenery, adequate inter-building gaps, appropriate design of internal corridor and environment-sensitive and personalised interior design need to be included in the SR habitat design and planning process as a baseline and evaluation criteria for ensuring socio-physical liveability among the displaced population. This study similar to Skalicky and Čerpes (2019), through systematic monitoring in the low-income resettled neighbourhoods, represents the initial approach in recognising and determining the hidden key-aspect of 'loss of socio-physical liveability' that leads to impoverishment among the displaced population. Additionally, unlike other typical slum rehabilitation policy-related researches, this study bridges the gap in developing an explicit measurement strategy through the delivery of feasible built-environment recommendations that would recover the impoverishment.

The results of the study are policy-specific; yet, the results have implications to a larger stakeholder group who are pursuing interaction of housing and urbanization. Understanding the concept, language and epistemology of the built-environment and socio-physical liveability interlinkages provide architects, city planners, and habitat policy-makers with a simulation-based and analytical approach to the planning process for forth-coming SR housings. The built-environment indicators analysed here are also intended in the public involvement into the planning process as well as to better understand the significance of socio-spatiality in achieving better socio-physical liveability, which is mostly ignored in low-income neighbourhood planning. Particularly, in Mumbai, where the current government housing authorities face exorbitant financial burden after the failure of SR housing projects, these early design checks implemented in design guidelines and policies can prevent further precarious rebound phenomenon.

In general, this study accentuates on the rarely-ventured 'socio-spatiality' aspect of the impoverishment of displaced. It also drives a way forward to alleviate this challenge, through liveability assessment using a composition of built-environment indicators that affect individual health, well-being and liveability. Using these built-environment indicators would enable developing new socio-physically liveable low-income SR housings and renovating the current SR housing stocks in deplorable conditions, and recover them into sustainable development, thus transforming 'space' to 'place'.

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Appendix 1. List of indicators for measuring social and physical liveability

Parameter: built-environment	Indicator		Social liveability	Physical liveability	Existing policy variable/guideline	Measuring tools	Reference
			(safety, social cohesion, local democracy, sense of belongingness, satisfaction and intimacy, inclusiveness, equity)	(healthy environment, mental, respiratory and heat-stress related health)			
Integrated open space	OS-1	% open space within SA	Leisure and recreation, well-being, social interaction	Respiratory health, heat related illness, mental health, sedentary behaviour, chronic conditions	Provision for open space	DA, SSA	(Villanueva et al., 2015)
	OS-2	Presence of green areas and public parks		Healthy environment		DA	
	OS-3	% open space area of sub divisible land area	Leisure and recreation, well-being, social interaction	Respiratory health, heat related illness, mental health, sedentary behaviour, chronic conditions		DA, SSA	(Villanueva et al., 2015)
	OS-4	No. of open space available within land area	Neighbourhood liveability	Healthy environment		DA	(Hooper et al., 2015), (Villanueva et al., 2015)
	OS-5	No. of local, neighbourhood, district, regional park	Leisure and recreation, well-being, social interaction	Walking and physical activity, healthy environment		DA, SSA, FO	(Hooper et al., 2015; Hooper et al., 2018; Villanueva et al., 2015)
	OS-6	No. of open space by size/type within neighbourhood	Leisure and recreation, well-being, social interaction	Respiratory and mental health, heat related illness, sedentary behaviour		DA, SSA	(Villanueva et al., 2015)
	OS-7	Amount of integrated green space (public or private)	Quality of life, neighbourhood residential liveability	Healthy environment, microclimate		DA, FO	(Norouzian-maleki et al., 2018), (Badland et al., 2014) (Ng, 2010)
	OS-8	Presence of trees and natural elements	Neighbourhood residential liveability	Healthy environment, microclimate	✗	FO	(Norouzian-maleki et al., 2018, 2015)
	OS-9	Presence of water features	Neighbourhood residential liveability	Healthy environment, microclimate	✗	DA, FO	(Norouzian-maleki et al., 2018, 2015)
	OS-10	Management of the space	Neighbourhood residential liveability	✗	✗	SSA	(Norouzian-maleki et al., 2018, 2015)
	OS-11	Sense of hierarchy between public and private space	Neighbourhood residential liveability, privacy for residents	✗	✗	Da, SSA	(Norouzian-maleki et al., 2018, 2015)
	OS-12		Neighbourhood residential liveability	✗	✗	SSA	(Norouzian-maleki et al., 2018, 2015)
	OS-13	Quality of access to the residential public spaces	Neighbourhood residential liveability, safe environment	✗	✗	SSA, FO	(Norouzian-maleki et al., 2018, 2015)
	OS-14	Easy way-finding in the neighbourhood spaces	Neighbourhood residential liveability, well-being	Mental health	✗	FO, Q	(Norouzian-maleki et al., 2018, 2015)
	OS-15	Visibility of public space	Neighbourhood liveability	Physical health	✗	SSA, FO	(Hooper et al., 2015)
	OS-16	Access to parks	Safe environment, neighbourhood liveability	Mental health	✗	DA	(Foster et al., 2016)
	OS-17	Percent houses within a distance from any neighbourhood park	Neighbourhood liveability	✗	✗	SSA	(Hooper et al., 2015)
	OS-18	Universal design: designing open space accessible to all	Residential environment liveability, human oriented environment	✗	✗	FO	(Skalicky & Čerpes, 2019)
	OS-19	Social space	Residential environment liveability	Mental health	✗	SSA	(Skalicky & Čerpes, 2019)
	OS-20	Accessible parks and public open spaces	Social interaction	Healthy environment	✗	FO, SSA	(Ahmed, 2012)
	OS-21	Appropriate quality/quantity of public open spaces	Social interaction	Healthy environment	✗	DA	(Ahmed, 2012)
	OS-22	Appropriate design and structuring of parks	Surveillance measures for safe neighbourhood	Healthy environment through efficient air movement	✗	FO, AS	(Ahmed, 2012)
	OS-23	Ratio of positive to negative space	Social interaction, safe environment	Healthy environment through efficient air movement	✗	SSA, AS	(Bardhan et al., 2018), (Carmona, 2010)
	OS-24	Porosity: area of voids in a neighbourhood	Neighbourhood liveability and satisfaction	Healthy environment	✗	DA, AS	(Bardhan et al., 2018)
	OS-25	Lighting of open space	Sense of safety	✗	✗	FO	(Skalicky & Čerpes, 2019)
Built-form	BF-1	Housing form and density	Neighbourhood residential liveability, Vitality and	Healthy environment through efficient air	Density	DA, SSA, AS, DS	

			social interaction among residents	movement and pollution removal, social determinants of health			(Norouzian-maleki et al., 2018, 2015), (Badland et al., 2014), (Ahmed, 2012)
	BF-2	Proportion and scale of space enclosed by buildings	Neighbourhood residential liveability, Social interaction	Healthy environment through efficient air movement, pollution removal and daylight	✗	DA, AS, DS	(Norouzian-maleki et al., 2018, 2015), (Foster et al., 2016), (Bardhan et al., 2018)
	BF-3	Number of storeys/building height	Sense of connection, intimacy	Healthy environment through efficient air movement and pollution removal	Floor area ratio	DA, AS	(Ng, 2010), (Aflaki et al., 2014), (Norouzian-maleki et al., 2018, 2015)
	BF-4	Difference in building height in neighbourhood	Safe environment, privacy for residents	Healthy environment through efficient air movement and pollution removal	✗	DA, AS	(Ng, 2010), (An et al., 2019)
	BF-5	Provision of mixed-use buildings	Safe environment	✗	✗	FO	(Norouzian-maleki et al., 2018, 2015)
	BF-6	Colour and material harmony	Residential satisfaction	Mental health	✗	FO, Q	(Norouzian-maleki et al., 2018, 2015)
	BF-7	Building morphology and arrangement	Housing quality, residential satisfaction, vitality and social interaction	Healthy environment, urban ventilation	✗	DA, AS	(Chan & Liu, 2018; Ramponi & Blocken, 2012; Ramponi, Blocken, de Coo, & Janssen, 2015; Yuan & Ng, 2012)
	BF-8	Community design: configuration of neighbourhood centre	Social interaction	Healthy environment, urban ventilation	✗	DA, AS	(Foster et al., 2016)
	BF-9	Houses plots arranged to face front sides and parklands	Safe environment, surveillance for residents	Site-based ventilation	✗	DA, FO, AS	(Ahmed, 2012)
	BF-10	Different residential plot sizes	Housing quality, residential satisfaction	✗	✗	DA	(Ahmed, 2012)
	BF-11	Good views through the plot	Housing quality, residential satisfaction	Mental health and well-being	✗	FO	(Ahmed, 2012)
	BF-12	Varying density near activity centre of a neighbourhood	Housing quality, residential satisfaction, vitality and social interaction	✗	Density	DA, FO	(Ahmed, 2012)
	BF-13	Compactness ratio: ratio of area and perimeter of an urban form	Sense of intimacy, quality of life	Urban ventilation	Floor area ratio	DA, AS	(Bardhan et al., 2018)
	BF-14	Shape index: ratio of perimeter to area	Sense of intimacy, quality of life	Urban ventilation	Floor area ratio	DA, AS	(Bardhan et al., 2018)
	BF-15	Slenderness ratio: ratio of height and width of shape of an urban form	Sense of connectivity, quality of life	Urban ventilation	Floor area ratio	DA, AS	(Bardhan et al., 2018)
	BF-16	Fractalness: measure of the degree of self-similar repetitiveness of an element in housing form layout or the complexity of a spatial structure	Quality of life	Urban ventilation	✗	DA, AS	(Rian, Park, Uk, & Chang, 2007), (Bardhan et al., 2018)
	BF-17	Brokenness: measure of the degree to which an urban form can be fragmented.	Quality of life	Urban ventilation	✗	DA, AS	(Bardhan et al., 2018)
	BF-18	Frontal area index	Quality of life	Urban ventilation	✗	DA, AS	(Bardhan et al., 2018), (Chen & Norford, 2017), (Wong, Nichol, Wong, & Nichol, 2013)
	BF-19	Form factor: ratio of surface area to the volume of urban form	Quality of life	Urban ventilation	Floor area ratio	DA, AS	(Bardhan et al., 2018)
	BF-20	Courtyard design, size and type	Liveability	Micro-climate, ventilation and daylight, thermal comfort, healthy environment	✗	DA, AS	(Rashid, 2011), (Rajapaksha, Nagai, & Okumiya, 2003)
Street network	SN-1	Canyon/aspect ratio i.e. height of building: width of adjacent road	Safe environment	Healthy environment, microclimate, airflow	Floor area ratio	SSA, AS	(Ng, 2010), (Norouzian-maleki et al., 2018, 2015), (Bardhan et al., 2018)
	SN-2	Total footpath provision	Human oriented environment	Physical health of residents	✗	DA	(Hooper et al., 2015)
	SN-3	Well connected pedestrian network	Safe environment	Physical health of residents	✗	FO, DA	(Ahmed, 2012)
	SN-4	Well-lit pedestrian network	Safe environment	✗	✗	FO	(Ahmed, 2012)
	SN-5	Appropriate width of the footpaths and side walks	Human oriented environment	Healthy environment	✗	DA	(Ahmed, 2012)
	SN-6	Streetscape design	Safe environment	Healthy environment	✗	DA	(Hooper et al., 2015)
	SN-7	Vegetation and fencing	Privacy for residents	Healthy environment, Microclimate, airflow	✗	FO	(Ahmed, 2012)
	SN-8	Promoting movement: walking and cycling in side alleys	Integration into wider urban structure and environment	Healthy environment	✗	SSA, FO	(Skalicky & Čerpes, 2019)
	SN-9	Temporary use and shared use of space	Flexibility of residential environment	✗	✗	FO	(Skalicky & Čerpes, 2019)
	SN-10	Walking friendly environment	Safe environment, human oriented environment	Healthy environment	✗	DA	(Skalicky & Čerpes, 2019)
	SN-11	Interconnected streets pedestrian and cyclist networks	Social interaction, sense of belongingness		✗	DA, FO, AS, DS	(Ahmed, 2012)

				Healthy environment in terms of airflow and daylight			
	SN-12	Connection to surrounding neighbourhoods and activity centres	Social interaction	✗	✗	FO	(Ahmed, 2012)
Building-level internal corridor	BC-1	Average corridor width	Residential satisfaction	Healthy environment	✗	DA, FO	(Saika, Alam, & Matsuyuki, 2018)
	BC-2	Lighting in corridor/lobby	Residential satisfaction, sense of safety	Healthy environment	✗	DS	(Phillips, Siu, Yeh, & Cheng, 2005)
	BC-3	Corridor design	Social interaction, sense of belongingness	Healthy environment	✗	DA, AS, DS	(Mohit, Ibrahim, & Rashid, 2010), (Zhou et al., 2014),
	BC-4	Corridor as communal space	Sense of belongingness, social interaction, residential satisfaction	Healthy environment	✗	FGD, FO	(Sunikka-blank et al., 2019)
Interior-level dwelling unit condition	DC-1	Partition wall design	Privacy, sense of safety	Pollution exposure level, healthy environment	✗	Q, AS	(Aryal & Leephakpreeda, 2015), (Lueker et al., 2020; Sarkar & Bardhan, 2020), (Sesotya et al., 2017)
	DC-2	Ventilator (air-outlet) design	Indoor privacy	Healthy environment	✗	FO, AS	(Priyadarsini et al., 2004), (Sarkar & Bardhan, 2020)
	DC-3	Furniture layout	Social interaction	Healthy environment	✗	FO, AS	(Eindhoven, 2002; Sarkar & Bardhan, 2020; Zhuang, Li, & Tu, 2014)
	DC-4	Toilet location	Sense of privacy and safety	Healthy environment	✗	FO, AS	(Abdul & Mahfoud, 2015; Gan et al., 2016)
	DC-5	Kitchen design, size and location	Sense of privacy and safety	Healthy environment, pollution exposure levels	Minimum kitchen size	FO, AS	(Abdul & Mahfoud, 2015; Gan et al., 2016)
	DC-6	Adequacy of number of rooms	Residential liveability and satisfaction, crowdedness	Healthy environment, mental health	✗	FO, Q	(Ogu, 2010), (Evans, 2003)
	DC-7	Comfort in house	Residential satisfaction	✗	✗	Q, FGD	(Maria & Aragonest, 1997; Tao, Wong, & Hui, 2014; Zalejska-jonsson & Wilhelmsson, 2013)
	DC-8	Privacy in residence	Residential satisfaction	✗	✗	Q, FGD	(Ibem & Amole, 2020)
	DC-9	Natural lighting inside the house	Sense of safety	Healthy environment	✗	DS	(Of & Aduwo, 2013)
	DC-10	Ventilation in and around the house	✗	Healthy environment	✗	AS	(Bardhan et al., 2018)
	DC-11	Appropriate orientation of unit for solar access and prevailing breeze	✗	Healthy environment	✗	DA, DS, AS	(Ahmed, 2012)
	DC-12	Window size, type and location	Liveability, privacy, residential satisfaction	Micro-climate, healthy environment, indoor lighting and ventilation, thermal comfort	✗	DA, DS, AS	(Madeddu, Gallent, & Mace, 2015), (Stavrakakis, Zervas, Sarimveis, & Markatos, 2012; Wang, Zhang, Wang, & Battaglia, 2018)

Notes: DA = design analysis, SSA = space syntax analysis, FO = field observation, Q = questionnaire, FGD = focus group discussion, AS = airflow simulations, DS = daylight simulations.

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