



Building Science for low-income habitat

By,

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TOWARDS SUSTAINABLE LOW-INCOME HABITAT DESIGN

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Overview

Lack of standardised sustainable habitat design guidelines for low-income housing plays a vital role in determining the poor quality of life in these settlements, particularly in the slums. Our work investigates process-driven pathways for developing and delivering sustainable habitat design guidelines using socio-technical frameworks. We employ mixed-mode research methods to understand low-income habitat from the perspective of people, places and practices. We combine urban experimentation with sound simulation techniques to derive practical solutions for improving the quality of life (QoL) of the urban poor.

Urban experimentation includes data acquisition through in-situ environmental sensing of the low-income habitations, modelling of the houses, calibration of the sensed data, and its urban scale building energy calculations using state-of-the-art building energy simulation techniques. We integrate the socio-cultural stochastics in the building-simulation framework to derive empirical evidence of the urban QoL in these settlements. There are three cohorts of our research: 1) Investigation of building performance; 2) Spatial analytics for urban sustainability and policy analysis; 3) Data-driven simulation and modelling techniques for derivation of low-income sustainability heuristics.

Investigation of building performance

In our lab, we are considering pathways for energy conservation by integrating daylight and natural ventilation into the building fabric of the low and middle-income population groups. The development of Energy Management Matrix (EMM), is a step towards integrating daylight as a critical element of energy conservation in the buildings. It is envisaged as an energy-saving building bye-law for middle and low-income settlements. Here, we have used state-of-the-art daylight simulation toolkits, to model and forecast the occupants' behaviour in switching off the lights in a typical middle-income apartment. This behavioural characteristic was further developed into the EMM and the proposed policy toolbox (see Fig.1) (Bardhan & Debnath, 2016).

The simulated illuminance levels are illustrated in Fig. 2. It forms the parametric part of the study, where the orientation of the building is changed, to estimate the effect of orientation on 'usable' daylight on the living space (Ramit Debnath & Bardhan, 2016). The final daylight performance of the building understudy for the parametric variables is illustrated in Fig. 3.

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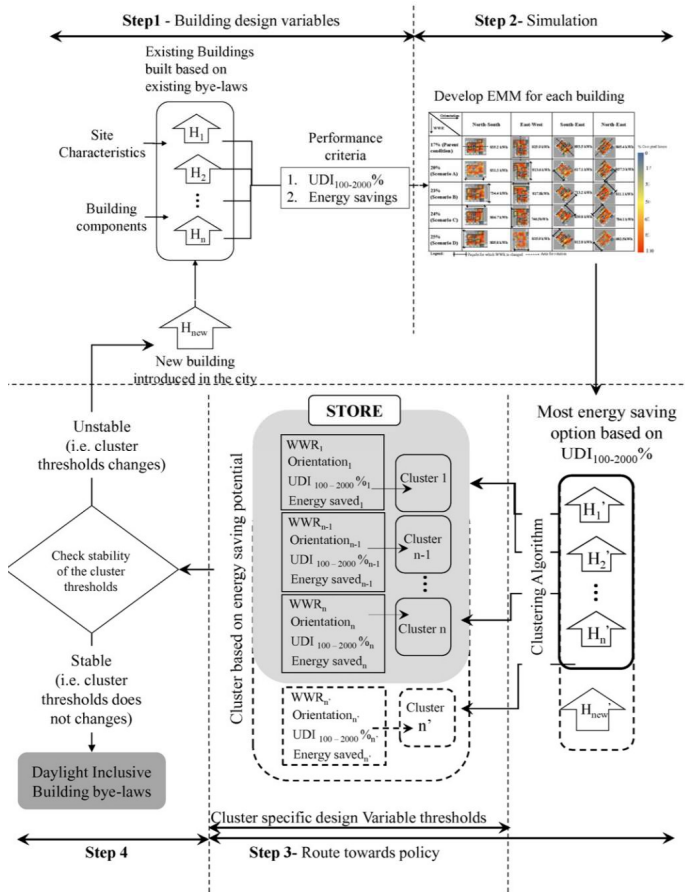


Fig. 1 Policy pathway for saving energy through daylighting using EMM (source: Bardhan & Debnath, 2016).

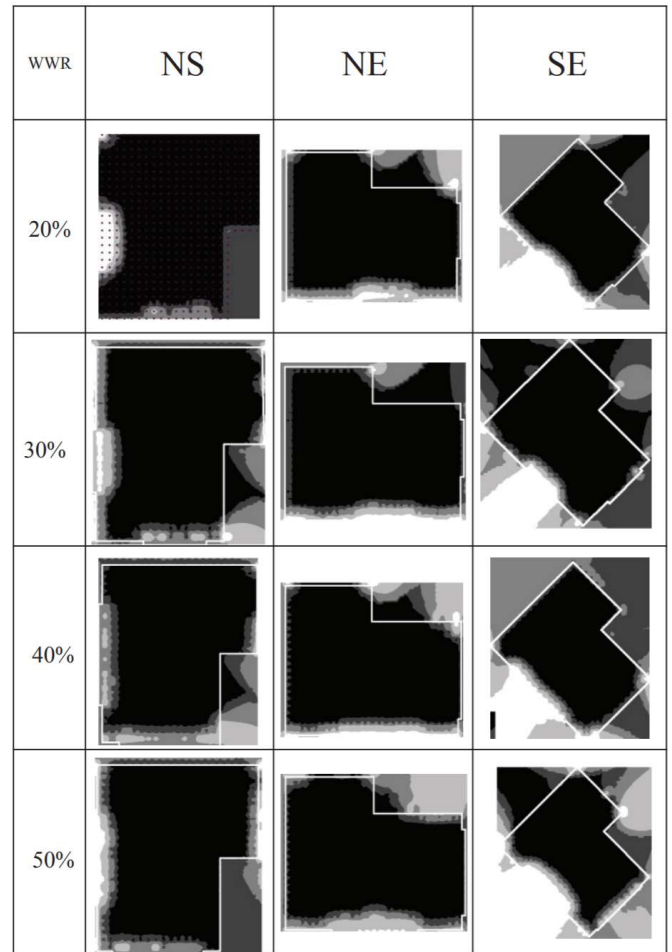


Fig. 3 Daylight performance of the building with respect to varying orientation and window to wall ratio (WWR). The white portion represents accepted illuminance levels ≥ 500 lux (Source: Debnath & Bardhan, 2016)

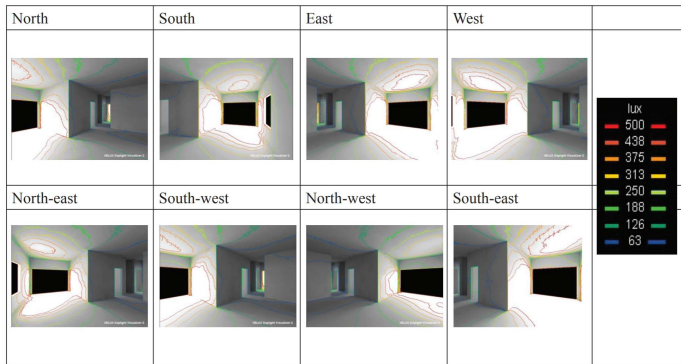


Fig. 2 Simulated illuminance levels of the building under investigation. (source: Debnath & Bardhan, 2016)

We have also assessed the energy performance of typical low-cost prefabricated housing, designed to cater to the ambitious ‘Housing for all -2022’ program of the Government of India. It was found that none of the specified material could maintain an indoor temperature between the recommended range of 26-28° C on a hot-humid climate (Bardhan & Debnath, 2018). The parametric analysis performed here were based on the variation of low-cost building materials along with low-cost window glasses (see Bardhan & Debnath, (2016a) for detailed methodology). This study primarily pointed out the need for standardisation of construction materials for affordable housing options.

We extended the scope of this work, towards investigating the building performance of the rural houses sanctioned under the Indira Awas Yojana (IAY), of the Government of India. Here, we evaluate the building performance by evaluating thermal comfort ranges and indoor air quality of the IAY houses, using climate based dynamic energy simulations. EnergyPlus v8.7 with custom occupancy schedules. The rural kitchens were specially modelled using a novel heat flux model to estimate the effect of solid-fuel

burning on the indoor airflow pattern (Bardhan & Debnath, 2017). These buildings were simulated as natural ventilation model with wind-driven natural ventilation as the primary driver of indoor freshness and indoor thermal comfort. The three climatic zones considered in this study were: Composite (Madhya Pradesh), hot-dry (Rajasthan) and hot-humid (Tamil Nadu). Results showed that the average operative temperature of the living room for Madhya Pradesh, Rajasthan and Tamil Nadu varied between 42.12 – 22.91°C; 45.41 – 26.46°C and 39.72 – 27.22°C (see Fig. 4), respectively, during the summer months (Bardhan & Debnath, 2017). It was also observed that houses with outside kitchen had lower indoor temperatures and better indoor air quality.



Fig. 5 Rural kitchens and its indoor built-environment (source: Debnath et al., 2016)

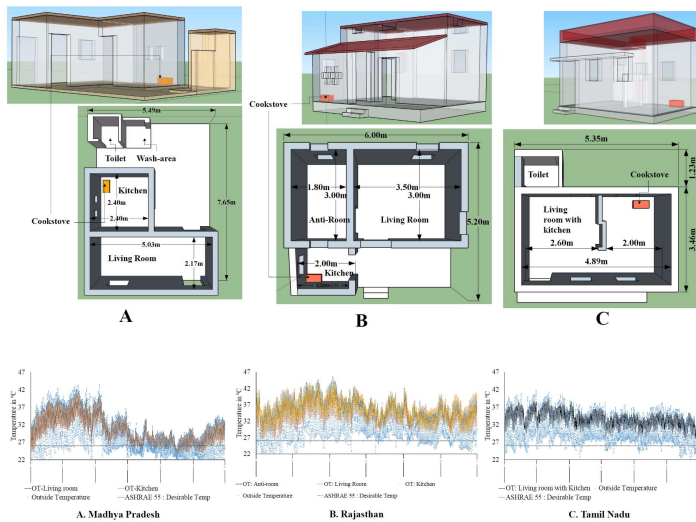


Fig. 4 Thermal performance of the IAY houses for the composite (A), hot-dry (B) and hot-humid (C) climatic zones

(Source: Bardhan & Debnath, 2017).

Our next step was a more in-depth investigation of such rural houses by employing mixed-mode research methodology to understand the airflow patterns for the various rural kitchen designs. Rigorous field surveys were conducted to document the rural built-environment (see Fig 5), and its associated socio-cultural practices. We then modelled these kitchens and investigated the indoor air quality using a subjective metric called the Local mean age of air (LMA) (see Fig 6). It was found that building parameters like the window to wall ratio, slenderness ratio, length and volume plays an important in maintaining the better indoor air quality, i.e. lower LMA (see Fig 7) (Ramit Debnath, Bardhan, & Banerjee, 2016).

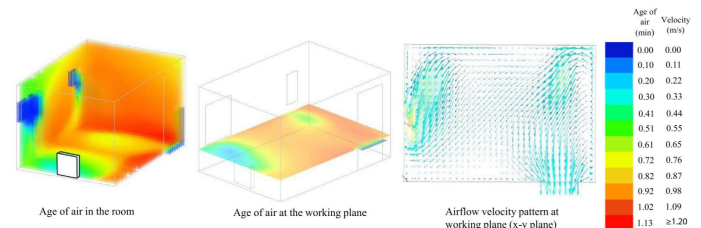


Fig. 6 Contours of local mean age of air, and airflow velocity during the time of cooking at working plane of 0.5 m (source: Debnath et al., 2016)

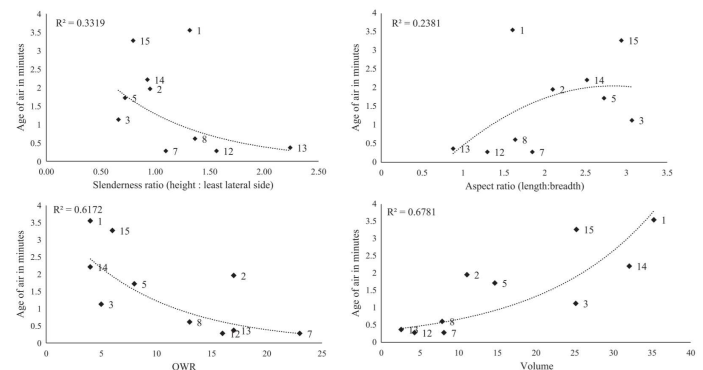


Fig. 7 Relationship of building parameters with age of air (source: Debnath et al., 2016).

The next step was the derivation of sustainable kitchen design heuristics through a socio-technical framework (see Fig 8). We propose a rural kitchen design framework that can enable construction of efficient kitchens that can reduce the exposure to household air pollution from the burning of solid fuel for cooking by enabling active cross - ventilation. This reduction of exposure is the virtue of better cross-ventilation through better design. Thus, occupants can get relatively better health without shifting to modern cooking fuels which may be expensive or inaccessible to them (Ramit Debnath, Bardhan, & Banerjee, 2017). Results showed a reduction of about 60% of indoor air pollution levels, through our derived kitchen designs (see Fig. 9). It was also found that such design based interventions can avert DALYs and child death (see Fig 10) (see Fig 10) (R. Debnath & Bardhan, 2016). Now, we are framing this socio-technical design methodology in the form of a rural-startup through an ICT based governance framework. We have

named it ‘Healthy Rural kitchen framework or HeR framework’ (This work is currently under review).

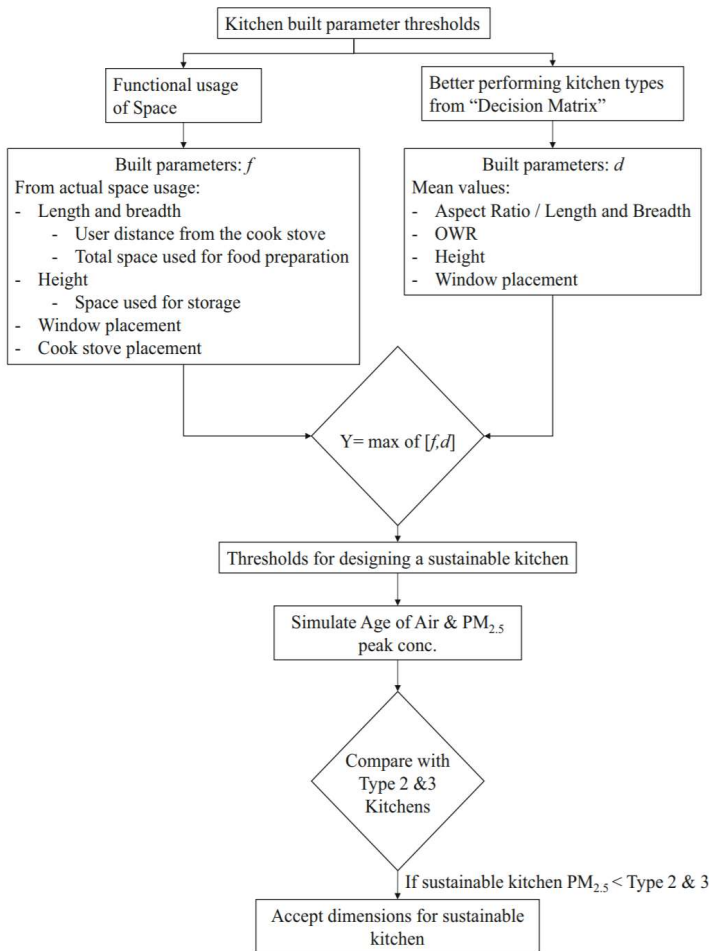


Fig. 8 Socio-technical design framework for healthy rural kitchen (source: Debnath et al., 2017).

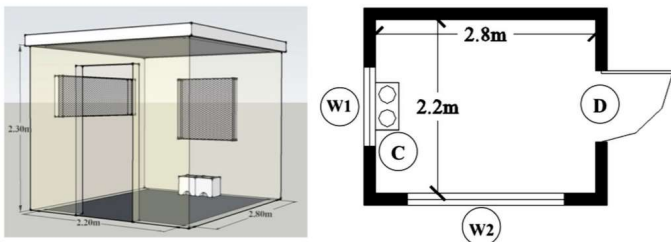


Fig. 9 Derived effective kitchen design (source: Debnath et al., 2017)

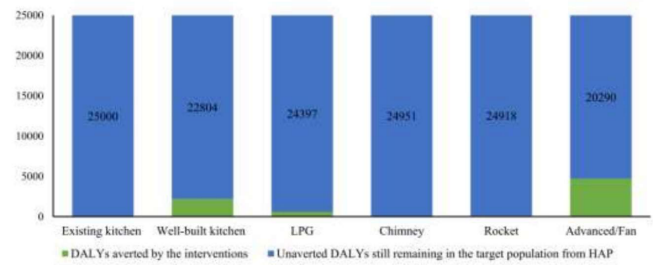


Fig. 10 Averted and unaverted DALYs by various interventions (source: R. Debnath & Bardhan, 2016).

Spatial analytics for urban sustainability and policy analysis

This part of our work focuses at a more significant urban scale, where we work on urban green (Bardhan, Debnath, & Bandopadhyay, 2016), urban flooding (Bardhan, 2017), urban land surface temperature and its association with the built forms (Mehrotra, Bardhan, & Ramamritham, 2016). In the urban green sustainability project, we had developed a risk susceptibility framework (see Fig. 11), which essentially enables a researcher or an urban planner to classify healthy green places in the context of rapid urbanisation. A case study of Kolkata (see Fig 12 and Fig 13) was presented in this study (Bardhan et al., 2016).

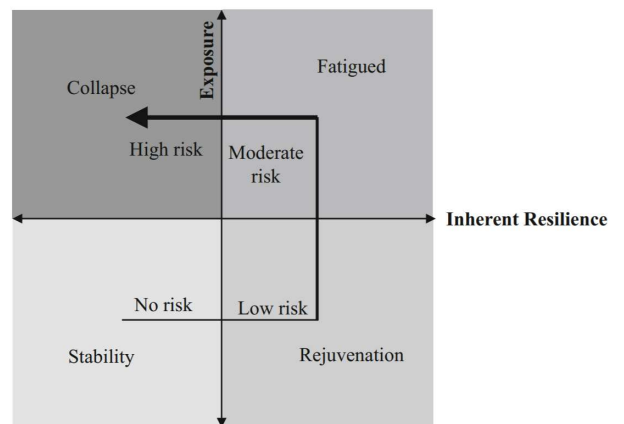
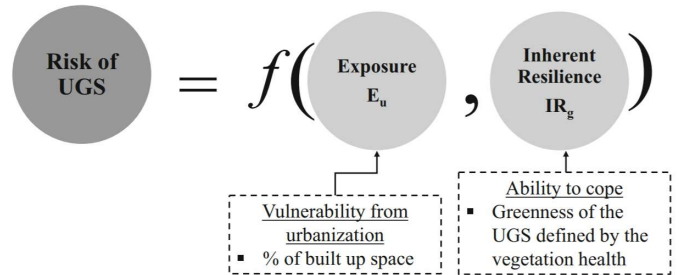


Fig. 11 Conceptual framework for assessing risk of urban green spaces (Source: Bardhan et al., 2016)

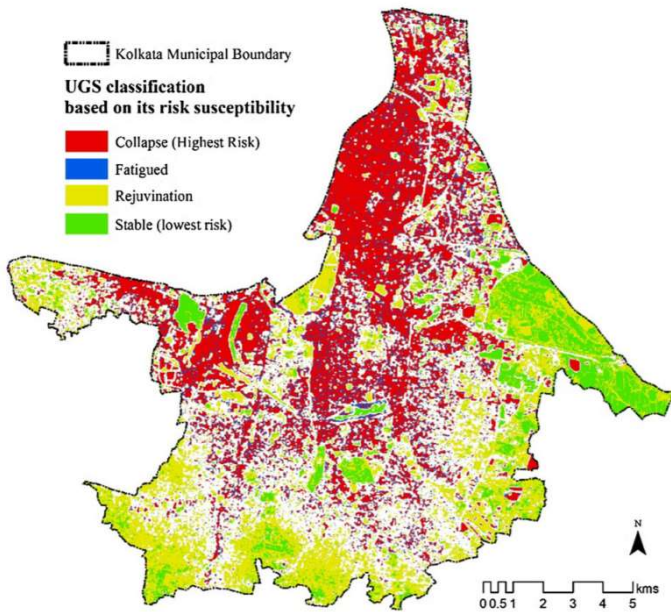


Fig. 12 Risk susceptibility of urban green spaces (UGS). (Source: Bardhan et al., 2016)

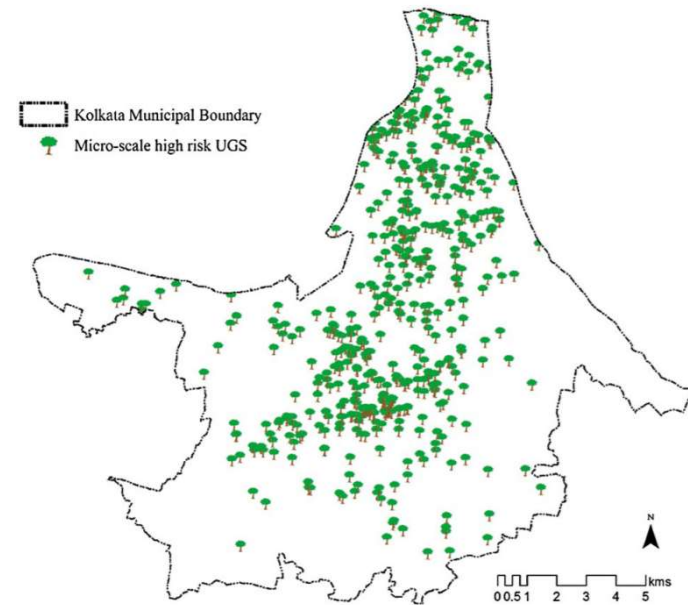


Fig. 13 Micro-scale high risk susceptibility mapping of urban green spaces (source: Bardhan et al., 2016).

An integrated framework for an urban-climate plan with a flood-prone assessment model (FPA) (see Fig 14) was proposed to integrate flood risk management technology with urban planning tools, which was a significant gap in the urban resiliency planning of India (Bardhan, 2017).

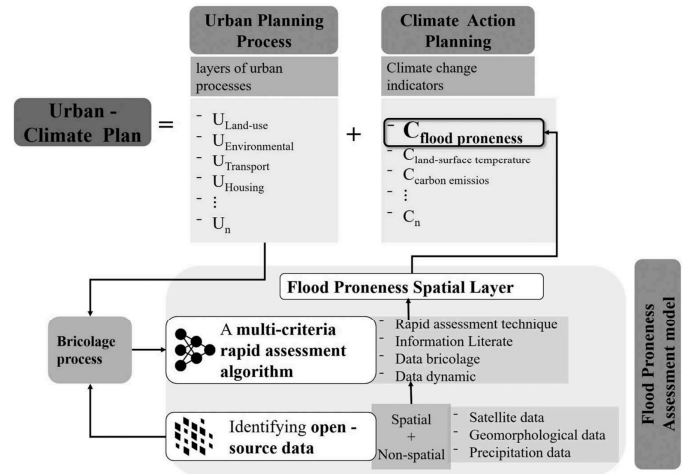


Fig. 14 Flood prone assessment model (source: Bardhan, 2017).

A bricolage-based data preparedness methodology was proposed for flood-prone mapping (see Fig 15), which also adds to the novelty of this work. This data preparedness methodology can act as an essential step in urban disaster resilience plan for data-constrained scenarios of developing nations (Bardhan, 2017). The research involved three main stages: the identification of open-source data on factors that contribute to flooding; rapid-prone mapping; and their incorporation into the urban planning system. The predicted flood proneness for Kolkata is illustrated in Fig 15.

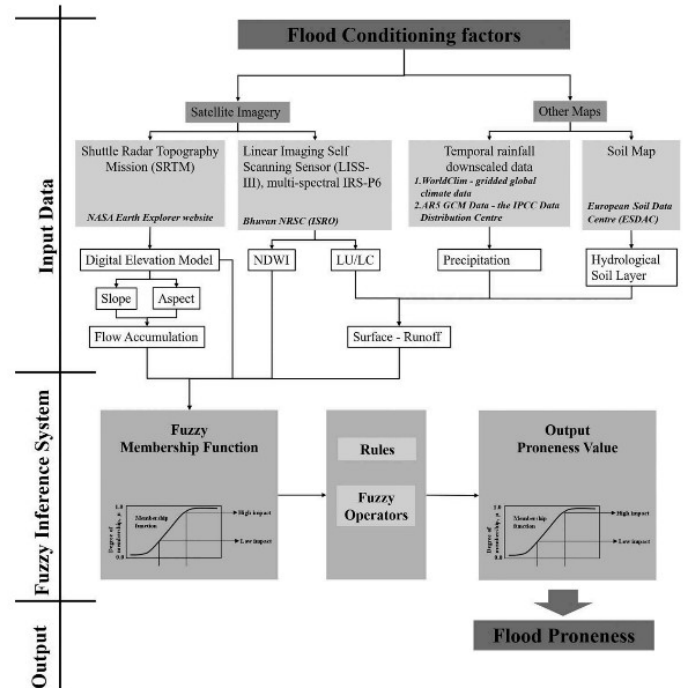


Fig. 15 Data-preparation methodology for mapping flood-prone (source: Bardhan, 2017).

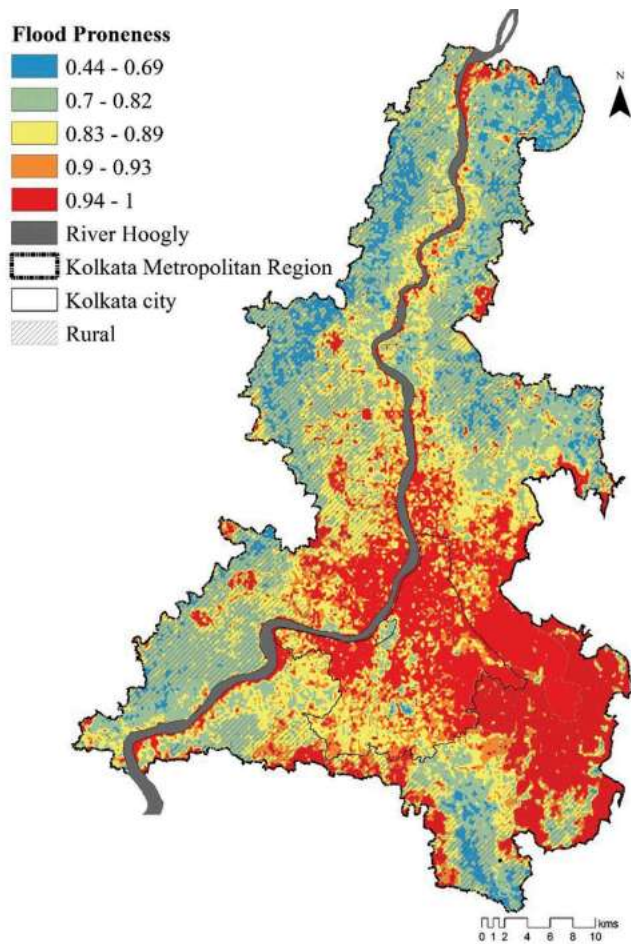


Fig. 16 Predicted flood proneness of Kolkata Metropolitan Region (KMR) (source: Bardhan, 2017).

Simultaneously, we are investigating the various built-forms of Mumbai in determining the variation in land surface temperature (LST) (see 17), where it was found that high built-up area percentage corresponds to high surface temperatures above 28°C (Mehrotra et al., 2016). On our ongoing work, we are calculating the sky-view factor for the entire city of Mumbai and intend to correlate with its LST derived from satellite imagery (LANDSAT-8 OLI/TIRS), and outdoor mean radiant temperatures. An illustration for the same is shown in Fig 18.

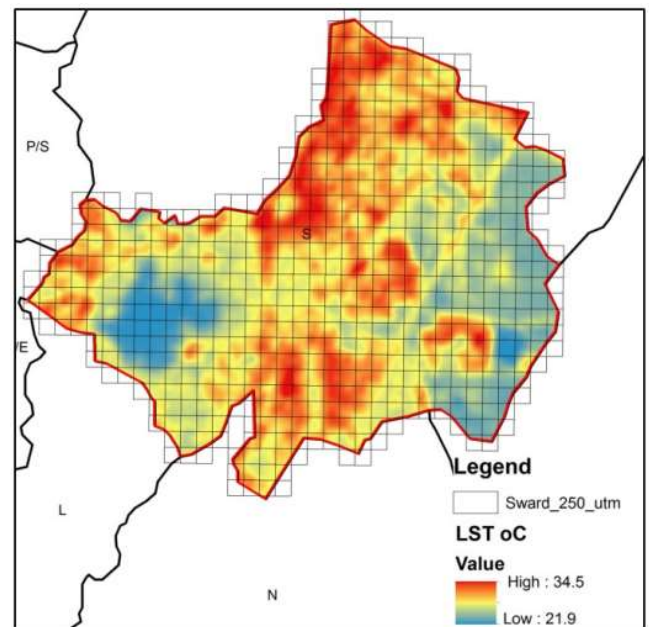


Fig. 17 Land Surface Temperature (LST) as estimated from Landsat 8 OLI/TIRS Feb, 2015 image (source: Mehrotra et al., 2016).

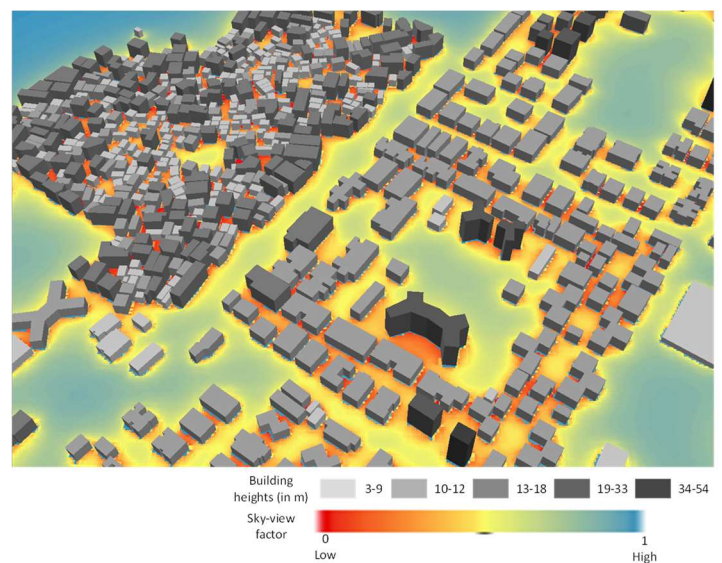


Fig. 18 Computation of sky-view factor, as a part of our ongoing work (Image courtesy: Nikhil Kumar, PhD candidate-CUSE).

We are also actively engaging in habitat policy analysis of the evolution of slums of Mumbai, since independence (1947). This study is aimed to provide a ready reckoner to the habitat policymakers to adopt critical lessons from the housing development history of Mumbai and work towards sustainable habitat guidelines for the city (Bardhan, Sarkar, Jana, & Velaga, 2015). See Fig. 19 for the evolution of housing policies in Mumbai, and Fig. 20 towards a suggested approach towards housing policy in Mumbai.

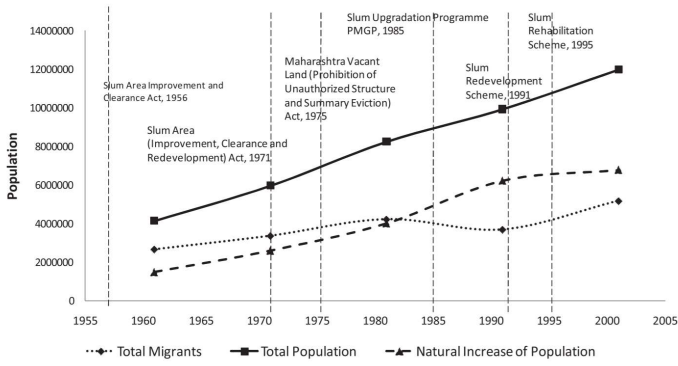


Fig. 19 Demography and housing policies in Mumbai (source: Bardhan et al., 2015)

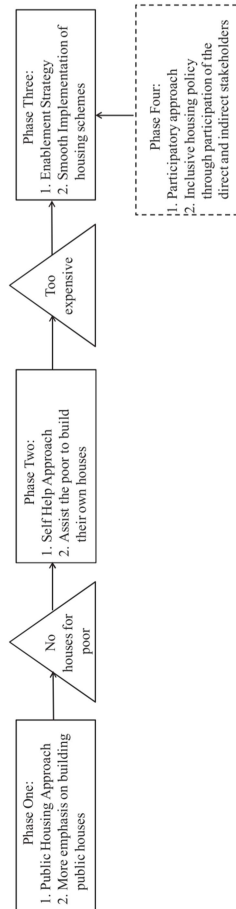


Fig. 20 Suggested approach towards housing policy in Mumbai (source: Bardhan et al., 2015)

In continuation of the previous research associated with the assessment of the housing policies of Mumbai, we proposed a framework to assess and locate affordable housing for developing nations (see Fig 21), with a case study on the housing scenario of Mumbai (Jana, Bardhan, Sarkar, & Kumar, 2016). See Fig 22 for the land price curve Mumbai, India.

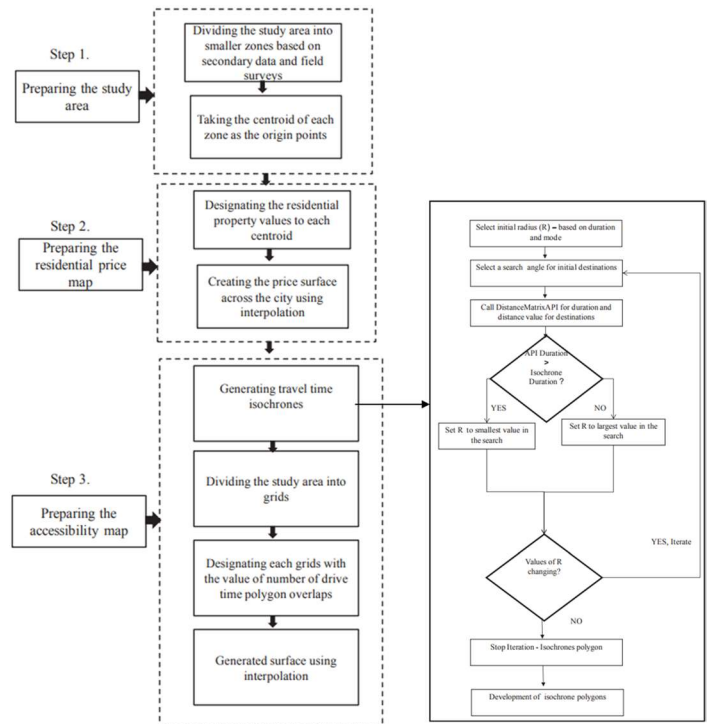


Fig. 21 Proposed framework using travel time isochrones (source: Jana et al., 2016)

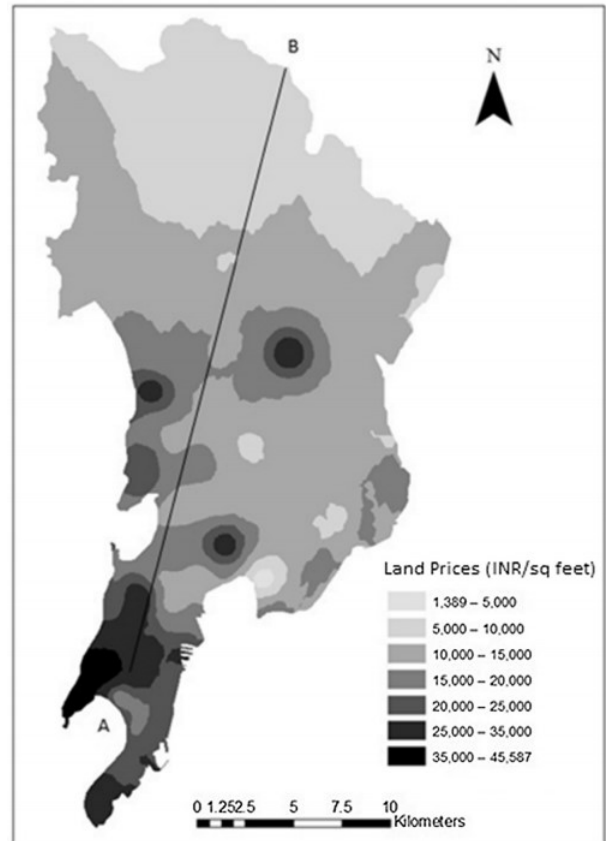


Fig. 22 Price curve for Mumbai (source: Jana et al., 2016)

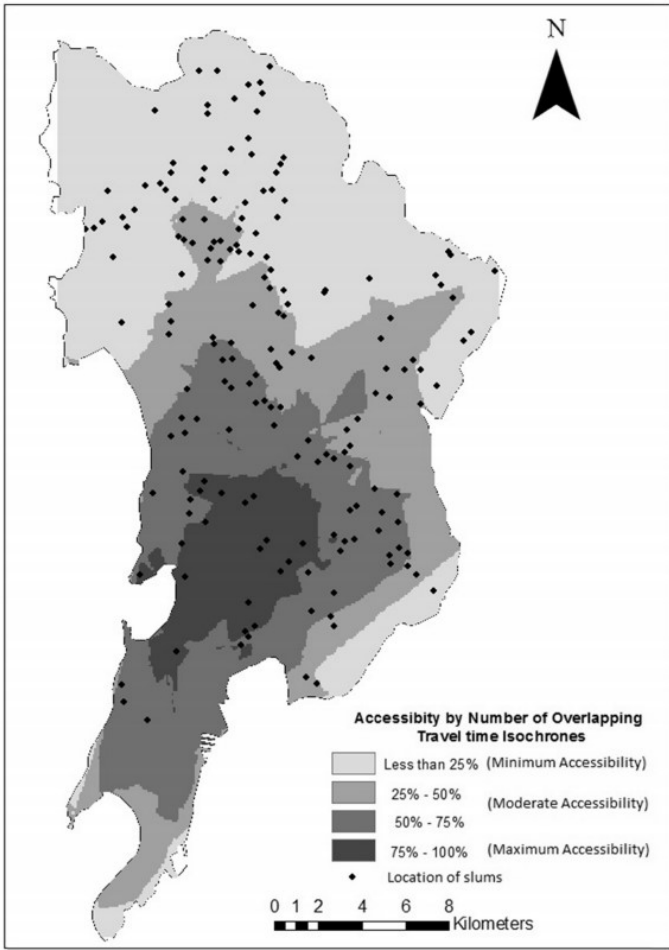


Fig. 23 Accessibility map based on 30 min isochrones (source: Jana et al., 2016)

We are also evaluating new agendas for city planning. The primary questions that we are dealing are that whether compact urban forms relate to the better urban quality of life (UQoL) in hyperdense cities of India. Our study empirically assesses the degree of association between the compact urban form (UF) and better UQoL at the neighbourhood scale in the case of Kolkata, an expanding, high-density city in India. Two UF metrics, the Compactness Index (COMPI) and the Mix-Use Index (MUI), which are based on the compact city model, are constructed to classify the city into UF prototypes of compact vs dispersed forms (Bardhan, Kurisu, & Hanaki, 2011, 2015). The methodological framework is illustrated in Fig 24. The UQoL clusters are illustrated in Fig 25, and the predicted probabilities of occurrences of UQoL clusters with UF at various socio-economic-cultural status (SECS) levels are illustrated in Fig 26.

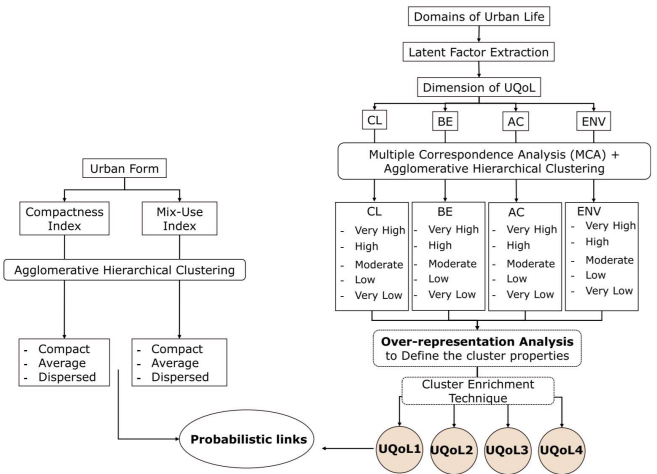


Fig. 24 The proposed methodological framework for assessing urban quality of life of compact cities (source: Bardhan, Kurisu, et al., 2015).

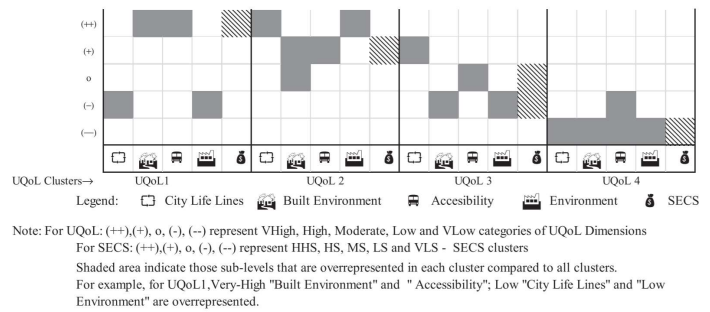


Fig. 25 UQoL clusters (source: Bardhan, Kurisu, et al., 2015)

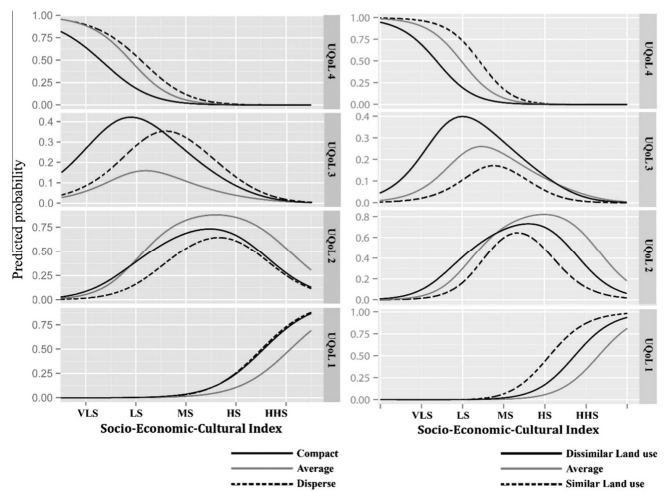


Fig. 26 Predicted probabilities of occurrences of UQoL clusters with UF at various SECS levels (source: Bardhan, Kurisu, et al., 2015)

Data-driven simulation and modelling techniques for derivation of low-income habitat sustainability heuristics.

In this cohort of our research, we are integrating data-driven pathways to assess the QoL of people living in low-income habitats. A part of this research is concentrated on experimental methods of data collection and urban sensing; while other part concentration on calibration techniques and uncertainty reduction. These form the basis of the input to building energy simulation models, making them robust and more accurate for real-time heterogenous situations like the urban slum energy modelling for Mumbai.

Data collected through environmental sensors form the core data-driven segment, where parameters like occupancy schedules, indoor illuminance levels, airflow in the living spaces through natural ventilation and accessibility to sunlight are measures using state-of-the-art sensors. We are working on developing a data-driven simulation methodology for deriving sustainable design thresholds for the slums in Dharavi, such that we forward the state-of-the-art in building simulation toolkits. It will have broad range of vertical and horizontal implication in terms of useful policy guidelines for slum rehabilitation and redevelopment projects. The conceptual form of our sustainable slum-habitat design framework is illustrated in Fig. 27.

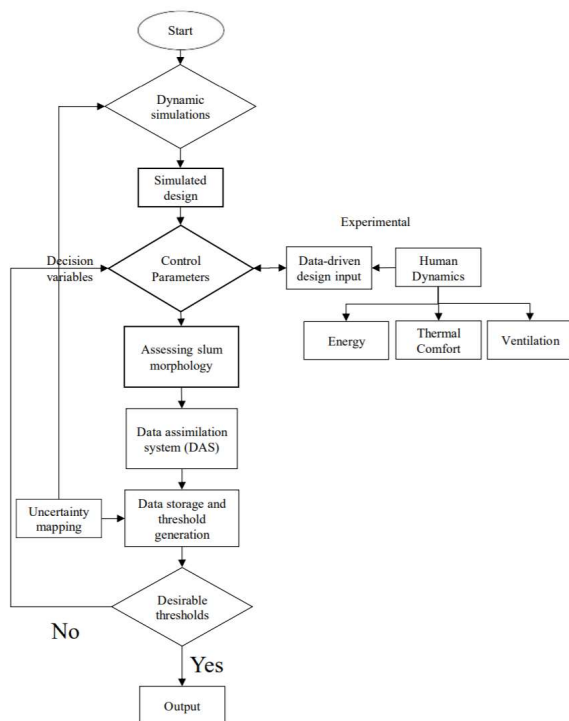


Fig. 27 A conceptual framework for sustainable slum habitation design (source: Ramit Debnath, Bardhan, & Jain, 2016).

The data acquired through the field sensors (see Fig 28) show high invariability between the diurnal temperature variation and the indoor air temperature in the slum houses (see Fig 29). This shows the need for interventions concerning affordable and efficient building materials, enabling airflow in the living and working spaces and improve the built-environment based on effective planning measures.

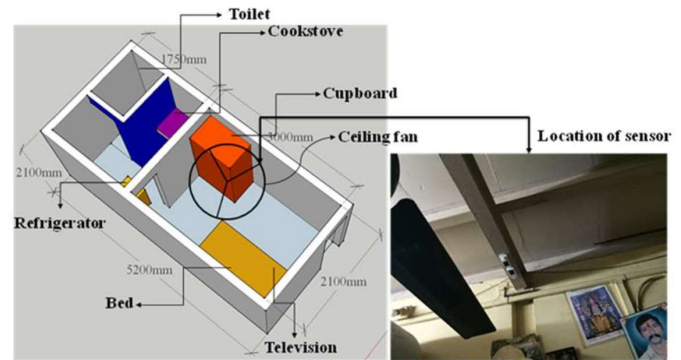


Fig. 28 Installation of field sensors in one of the slum houses of Dharavi, Mumbai (source: Ramit Debnath, Bardhan, & Jain, 2017).

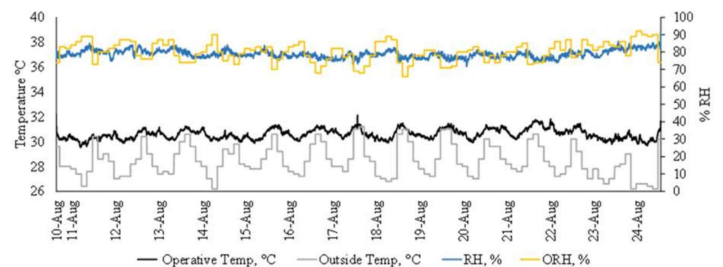


Fig. 29 Data collected through sensors in one of the slum houses in Dharavi, Mumbai (August 10, 2016 to August 23, 2016) (source: Ramit Debnath, Bardhan, & Jain, 2017)

To investigate this effect of variation of indoor air temperature we modelled and simulated horizontal slum forms (M1) and the proposed vertical slum forms (M2 and M3) (see Fig 30). Subsequently, detailed building energy performance simulations were carried out.

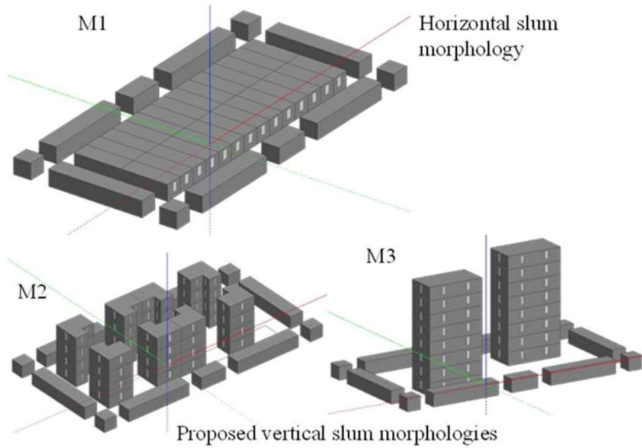


Fig. 30 Slum morphologies in Mumbai: horizontal structures (M1) and Vertical structures (M2 and M3) (source: Ramit Debnath, Bardhan, & Jain, 2017)

The built environment of both the horizontal and vertical structures are illustrated in Fig 31 and Fig. 32. Results show that horizontal form promotes lower operative temperatures, while the vertical forms have higher indoor temperatures. It can be attributed to the thermal massing and mutual shading effect of the hyperdense horizontal settlements. Moreover, the vertical structures inhibit the informal business of the horizontal slum, which compels the occupants to revert to the horizontal form (Ramit Debnath, Bardhan, & Jain, 2017). This forms the scope of our future research to study and integrate sustainable urban planning practices to enable community participation and shared spaces in the vertical forms, to enhance the sustainability of the slum rehabilitation houses, and improve the overall quality of life of the people living in these settlements.

Data-driven techniques for pro-environmental behavior

We have also devised a game-based persuasive technology to promote pro-environmental behaviour (PEB) among the school children (Bardhan, Bahuman, Pathan, & Ramamritham, 2015). We formulated the IER framework of Inform, Enable and Re-Act (see Fig. 32) and forwarded the Inform element using persuasive technologies. We use persuasive game design as a mode to transfer waste segregation behaviour from virtual to real world. The game was deployed and piloted with school children and is based on principles of sensory stimulation, simplicity, uncertainty, difficulty, generation of collective behavior and competitiveness. Upon deployment, the game received favourable response from the target user group where most of them indicated an interest to play the game again and would also recommend it to their peers. The game sequence is illustrated in Fig 33 and Fig 34.



Fig. 31 Built-environment of the horizontal slum houses of Dharavi, Mumbai (source: Ramit Debnath, Bardhan, & Jain, 2017).



Fig. 32 Built-environment of the vertical structures, emancipating a slum like living conditions (source: Author).

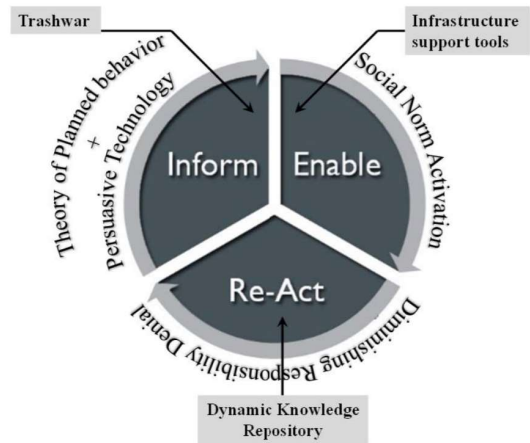


Fig. 33 Inform, enable and re-act framework of the PEB game (source: Bardhan, Bahuman, et al., 2015).

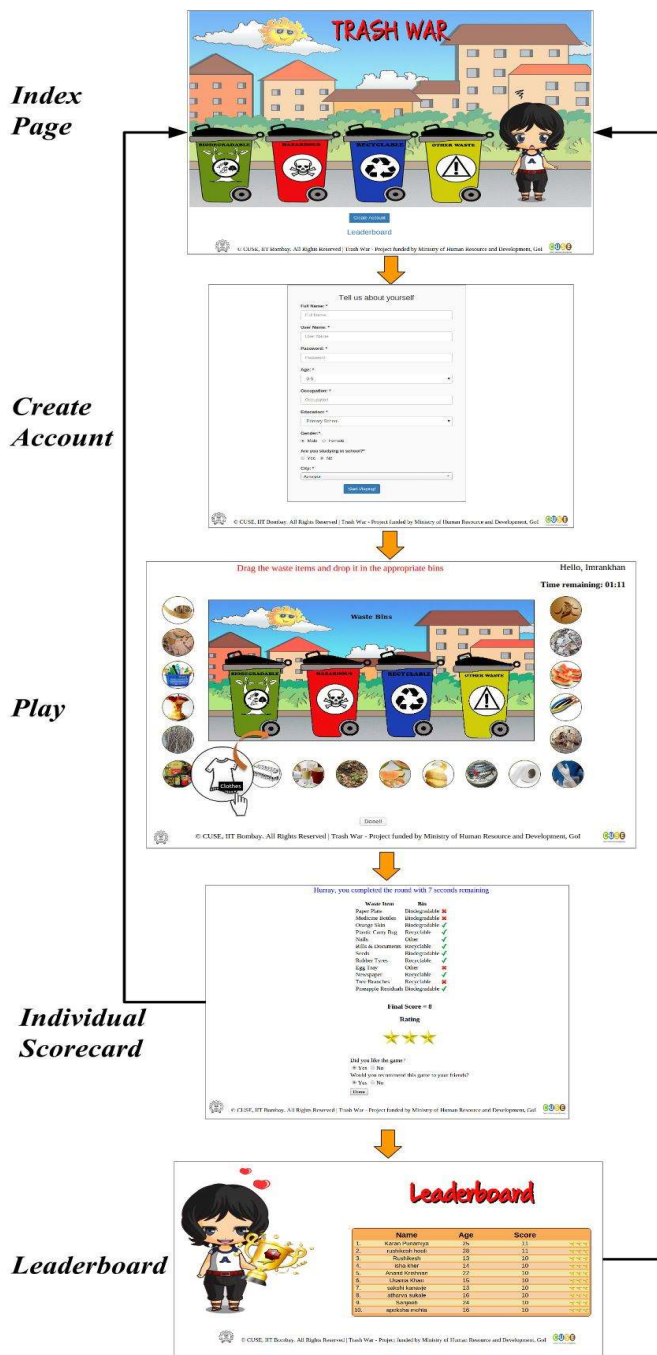


Fig. 34 Game sequence of the PEB game (source: Bardhan, Bahuman, et al., 2015). The game is available on the following link <http://cuse.iitb.ac.in/trashwar/game/>

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