Habitat Monitoring for TB Risk Mitigation and an Integrated Information-based Decision-Making Framework for Dense Urban Settings: An Approach

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The impact of the unclean and crowded living conditions, especially that experienced in the thickly populated slums of the developing countries, towards enhancing the risk of tuberculosis (TB) infection is well known, and the same has been documented previously [1-3]. Historically, TB has been a disease associated with poor people across the world. On an average about 2–3 million people succumb to this neglected yet lethal disease. Of this population, a large fraction belongs to the underprivileged habitats in the developing countries and the poor, urban neighbourhoods in wealthier, advanced powers [1].

Although identifying this issue has taken place, the strategies to deal with it from a habitat planning point of view are yet to be articulated in the form of actionable recommendations. The strategies adopted by the World Health Organization (WHO), the United States Agency for International Development (USAID), The Global Fund, and other large organizations towards controlling the spread of TB and the mitigating the risk of infection have been largely revolving around clinical solutions in the form of drugs, vaccines, and access to healthcare [1, 4]. Consequently, the impact of the physical environment of the habitat on the incidence and sustenance of TB in the individuals has been neglected by and large, in both industrialized and non-industrialized countries [1].

Despite 'crowding' being a crucial factor associated with infection risk for several decades, quantifying the impact of over-populated habitats on the incidence and propagation of TB is not simple. A straightforward data driven evaluation metric is yet to be formulated. However, there is an immediate need to formulate the template for a consolidated checklist that covers the critical questions pertinent to the incidence and aggravation of TB due to poor habitat conditions. Such a template will aid in streamlining the flow of information. From the organized pool of information, salient takeaway points pertinent to the control and management of TB can be derived, and those can be integrated with the existing monitoring frameworks that are used in assessing and improving the Quality of Life (QoL) in unacceptable and untidy crowded habitats.

Published literature indicates some of the established methodologies to monitor the progress of the targeted programmes aimed at improving the QoL for the urban slum dwellers. In this context, it is important to note that one of the key targets mentioned in the Millennium Development Goals (MDGs) brought forth by the United Nations is to 'achieve significant improvement in lives of at least 100 million slum dwellers, by 2020' [5, 6]. The operational definition for the sub-city level slum settings is often woven around a few key indicators, such as access to water and sanitation, sufficient living area, a house with durable material on a non-hazardous location and with tenure security. However, more recent studies provide a deeper insight regarding the TB risk factors emanating from indoor environments. Some of the key elements within the household physical environment that could emerge as TB aggravators are – existence of smoke inside the house for prolonged hours, use of solid fuel used for cooking, lack of separate spaces for cooking (often the living room and the kitchen are the same), use of mud or natural material for making floor, roof & the walls, large number of persons sleeping together in a room, sharing of toilets with other households, and shortage of drinking water [3].

To weave this detailed information intricately into the intervention strategy aimed at improving health and habitat in the underprivileged areas (e.g., slum pockets within the densely populated metropolitan cities, slum areas alongside the broad-gauge railway lines that run from the cities into the smaller municipal towns), intimate knowledge regarding the physical conditions of the neighbourhood is needed. A spatial information repository can be developed with extensive use of geospatial techniques that encompass geo-visualisation and may involve multiple layers of mapping.

A complete picture of the living conditions can be captured by working closely with the local planners, infrastructure engineers, and more importantly with the local communities. This information will provide insights into the hardship of communities in terms of the physical environment offered by the habitat, as well as into the criticality of TB-related environmental attributes that might pose a serious risk of community-scale TB infections and subsequent aggravation [3].
In the modern era of cutting-edge and emerging technologies, advanced technological tools are evolving that can aid in simulation and visualization of complex scenarios leading to informed decision-making, aided by adequately accurate prediction and intelligent actuation [7].

Augmented Reality (AR) can be used as a very efficient tool for habitat monitoring as it supplements the view of the physical world with computer-generated content, usually in the form of texts, images, audio-visuals, 3D objects etc. The modern day state-of-the-art smart mobile devices with high computational capabilities and three-dimensional interactive geospatial visualization (3D GIS) have opened up an array of novel possibilities [8].

The combination of ground truthing and the geospatial information in an integrated framework enabled with Artificial Intelligence (AI) capabilities can bring a revolution in the habitat monitoring. If TB monitoring can be integrated with this framework using the nuances derived from community-level surveys, that will enable bridging of gap between the administrative tier and on-ground operational tier engaged in eradicating the curse of tuberculosis across the world.

For these purposes, location-based marker-less AR technology may also be suitable as it does not require prior knowledge of a user's environment to overlay a 2D or 3D content into a scene (area of interest) and for holding it to a fixed point [8].

The fundamental goal of a generalized AR framework is to incorporate computer-generated input into real-world experience. Since this technology uses data from camera systems, dedicated sensors and deploy complex data interpretation (DI) algorithms for accurate detection and mapping of the physical environment, the resource requirements need to be evaluated at the planning stage. Since the technology can be accessed through devices like smartphones, laptops and even headsets, it is quite user-friendly.

Mapping is the most important feature associated with any marker-less AR tool/ app. In a location-based marker-less AR tool, the first step is Scene Recognition to recognize and track large objects like housings, rooms etc. [9]. Thereafter, simultaneous/synchronized localisation and mapping (SLAM) is needed.

SLAM denotes mapping of an area whilst keeping track of the location of the device within that area. Using such a technique mobile mapping is possible. SLAM allows a user to map large areas within reasonably shorter durations, as the areas can be mapped using mobile robots, vehicles, or even drones. SLAM systems are suitable for both outdoor or indoor environments and they simplify the data collection process [10]. Sensors deployed in a SLAM system use different sources of data (visual, non-visible) and at times they also utilize basic positional data, using an inertial measurement unit (IMU). Using the sensor data, the device computes a 'best estimate' of its own location. The estimate is improved as new positional information is collected frequently.

Once the mapping is done, specialized plugins may be used to create 2D/3D objects for incorporation into the scenes. These objects may include customized information (habitat- indoor physical environment and surroundings, TB-risk assessment data) based on the requirement, for enhancing the experience of the user.

Thereafter, Geolocation Application Programming Interface (API) allows the user to provide their location to web applications. Finally, the integration with open-source mobile app platforms is needed.

AR tools can provide information for both indoor physical environment and the habitat surroundings. The real-estate sector often uses popular AR browsers for gathering the vicinity information around chosen area. AR browsers have also been used for searches related to interior designs [11].

Using such tools, necessary development measures encompassing maintenance of cleanliness, remodelling of housings to add more space, improvement in sanitation and drinking water supply can be planned. This can happen in conjunction with the TB-related measures such as – collecting information regarding the infected individuals, collecting information regarding the locality, spacing of the houses, survey of population density and locality-wise quality of life (preferably at the ward level) etc.

Figure [1] schematically shows the conceptual template for the envisaged data integration for the necessary interventions. As evident from the figure, evaluation of the habitat monitoring framework and ground-level assessment of the TB Risk emanating from the habitat conditions are to be done periodically. Necessary course corrections should be incorporated in the template used for information integration. Once the reliability of the framework is established through pilot studies, the generated composite information can be used for decision making pertinent to remedial interventions, both for habitat improvement and TB risk mitigation.
Such a framework may also include open-source mobile technology for rapid TB diagnosis, which would prove to be a boon for the communities with limited resources, i.e., those residing in remote areas with few clinics, and diagnostic tests.

This would do away with a lot of logistical hurdles associated with the delay in processing the test samples, that tend to hinder the immediate treatment. In addition, this will also make the follow ups a lot more streamlined as the chance of the lab results getting compromised or lost is greatly reduced by enabling biometric verification process [4].

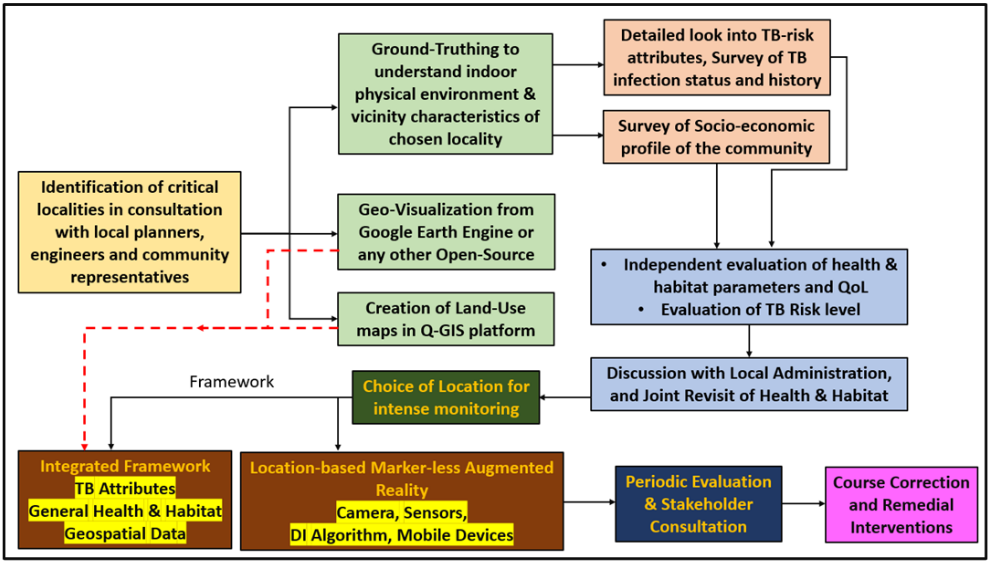

Figure [1]: Information Flow and Integrated Framework for Health & Habitat Monitoring and TB Risk Mitigation in Urban Settings

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