From City- to Health-scapes: Multiscale Design for Population Health

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Abstract

Reconciling the growing proportion of the global population that lives in urban centers with the goal of creating healthy cities for all poses one of the major public health challenges of the 21st century. Genetics has accounted for only 10% of diseases, and the remainder appears to be from the interaction of multiple socio-environmental causes that potentially determine epigenetic changes leading to diseases. Therefore, quantifying the dynamics of socio-environmental factors and the environment-disease linkages is extremely important for understanding, preventing and managing multiple diseases simultaneously considering population and individual biological information of exposed and non-exposed individuals. This is particularly important for the aim of reprogramming health-trajectories of populations via a quantitative health-based design of cities. Here we show how complex systems models, and specifically, dynamic network factor analysis (DNF) coupled to global sensitivity and uncertainty analyses can map the exposome-genome-diseasome network (i.e., the macrointeractome), determine network factor metrics useful for urban design, and assess probability distribution of comorbidities conditional to exposure in space and time, respectively. These probabilities are useful to make syndemic predictions by for design of socio-technical and ecological systems and intervention strategies in existing cities via scenario modeling of different design alternatives. As a case study, we use the SHIELD study in Minneapolis focused on measuring children's exposures to multiple environmental stressors and related effects on respiratory health and learning outcomes. Results show the very high degree of directional interaction among exposure factors and their spatial heterogeneity coupled to bi-directionally interacting diseases. We find non-linear conditional probabilities of disease co-occurrence and context-dependent dose-response curves that manifest large health disparities in populations. We show that macro socio-environmental features are much more important than biomarkers in predicting disease patterns with particular focus on respiratory diseases and learning outcomes. This emphasizes the fundamental importance of preventive population health versus downstream ersonalized medicine strategies. Urban texture results as the most important factor, thus, such metric should be clearly considered in the design of socio-environmental systems via a minimization of the systemic health risk.

The developed probabilistic models are extremely flexible for the analysis of big data, city healthscape predictions, and optimal management of communicable and non-communicable diseases in complex socio-ecological systems for systems design. The understanding of linkages between structural, architectural, social, and environmental factors at the population scale will allow designers, architects, engineers, and scientists to design communities - from the material to the city scale - in which population health is the central objective of the design process.

Keywords: complex systems, cityscapes, systemic risk, dynamic network factors, design, respiratory diseases, learning outcomes, urban texture, neighborhood