Transforming Health: Emerging technology, the built environment and health behaviors

Dorothy Thomas

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Andrew Dannenberg
Howard Frumkin

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Abstract

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Dorothy Thomas

Chair of the Supervisory Committee
Andrew Dannenberg
Environmental and Occupational Health

Context

Technological advances have a demonstrated capacity to influence patterns of behaviors by transforming the environments in which we live, work and play. Furthermore, technological innovations can also affect how well we address complex, emerging and persistent health concerns. Although there are an increasing number of studies that explore how our physical environments—both built and natural—inform health related behaviors and, subsequently, health, there is limited research on how technology alters this relationship. Namely, there is inadequate literature supporting and exploring how increasingly pervasive digital and mobile devices influence the association between health behaviors and the built environment.

Objective

This exploratory analysis investigates the ways in which technological advances modify the relationship between the built environment and health behaviors in order to ultimately influence population health.

Methods

Key informant interviews were conducted to explore the nature and breadth of the relationship between technology, the built environment and health related behaviors. Informants drew from their expertise, scholarship and experiences in order to provide examples of and insights on this relationship. They also offered suggestions for improving the proposed causal mechanism.

Conclusions

There is limited research exploring the relationship between technological advancements, built environment, and health. Here, we support the existence and importance of this relationship by proposing a causal pathway, presenting scenarios substantiating this association and outlining high priority research areas.

APPENDIX 1: Schultz & Northridge Conceptual Model

INTRODUCTION:

Some of the most pressing public health issues include adapting to and mitigating the consequences of climate change, confronting resource scarcity, eliminating inequities, and decreasing the burden of chronic and infectious disease. Increasingly, public health concerns of monumental and minute proportions are being addressed by leveraging technological resources. These emerging mechanisms and approaches can help address complex public health problems in novel and nuanced ways. For example, technological advances may help to more efficiently and effectively monitor resource consumption, modulate behavior patterns, and strategically and sustainably construct our environments. In order to highlight opportunities and challenges associated with these solutions, we will present examples that demonstrate how technology influences health behaviors as well as environmental context. More specifically, we will explore how an increasingly sophisticated digital landscape can modify the relationship between the built environment and health behaviors to ultimately influence individual and population health. Here, the "built environment" is operationalized as all of the physical structures that comprise the areas in which we live, work and play as well as the transportation modalities that link them.

In addressing public health issues, recent years have seen greater emphasis placed on health determinants that transcend the individual level (i.e., the built environment and public policy) (McLeroy et al., 1988; Feuillet et al., 2015; Golden et al., 2015). Public health researchers are increasingly shifting the focus of interventions away from individual-level factors and towards more "upstream" determinants of health (e.g., policy changes and improved neighborhood design) with population-level impacts (Watt, 2007; Williams et al., 2008). The shift to upstream determinants of health is driven by mounting evidence and acknowledgment that "place matters" and that environmental (e.g., social, political, environmental and economic) contexts must be considered when addressing public health concerns (Frumkin, 2003; Gordon-Larsen et al., 2006; Kramer & Hogue, 2008; Kent et al., 2013). Furthermore, place-based health interventions and policies have catalyzed natural partnerships between public health workers, urban planners, architects and engineers. The goal of these partnerships and resulting outcomes is to improve environmental contexts so that they are more explicitly people-centered and conducive to health and wellness (Abrams et al., 2012).

Changes in our technological landscape—for example increased penetration of data visualization tools that assist in more accurately characterizing behavioral patterns (Kratzke & Cox, 2012) as well as the near-ubiquity of smartphones (Sarasohn-Kahn, 2010; Smith, 2012)—improve our capacity to identify, assess and transform the relationship between health and the built environment. From advanced transportation technology to more intuitive and vibrant digital ecosystems, increasingly sophisticated innovations have important implications for shaping health. A better understanding of the ways in which health and the built environment are impacted by rapidly evolving technologies can help to better articulate future research needs, guide more intentional research inquiries and lead to more informed decisions about how to best address public health concerns.

METHODS:

Interviews

Convenience sampling was used to identify key informants as well as other information resources. An exploratory literature review was conducted prior to engaging key informants. Eight researchers, (primarily affiliated with the University of Washington in Seattle) experts, and

scholars in the fields of civil and environmental engineering (n=3), sociology (n=2), human centered design and engineering (n=2), and transportation policy and innovation (n=1) were first identified using the Internet. Over the course of two months, in-person consultations were subsequently requested and scheduled at a time and location that was convenient for the key informant. Based on content from the conversations with these primary contacts, suggestions for information resources as well as secondary contacts with other experts believed to have relevant knowledge were pursued. An in-person meeting with these secondary contacts was subsequently requested and this process repeated.

The primary goal of these interviews was to allow the key informant an opportunity to share their insights and recommendations about the subject matter of this project. The interviews lasted from thirty minutes to one hour and were conducted on different days of the week by the same researcher. They were semi-structured, informal and exploratory in nature. During the consultation, the interviewer articulated the research topic, described the proposed causal pathway and provided examples of the technology/built environment/health behavior association. Key informants were asked to reflect on this information and provide detailed responses and feedback. Informants were also asked to identify real-world examples of the proposed causal mechanism (i.e., technology/built environment/health behavior association) in effect. The interviews were not recorded; however, the researcher collected hand written notes during the meeting and additional notes were organized and incorporated after the meeting.

Content from interviews (i.e., feedback on the causal model, real-world examples of the proposed effect as well as suggested resources) were integrated with literature review findings and informed further development of **a)** the causal mechanism for how technological infrastructure modifies the relationship between the built environment and behavior (Figure 1) and **b)** the table of factual examples supporting this relationship (Table 1). Figure 1 was adapted from a framework linking the built environment to social determinants of health (Schultz and Northridge, 2004). Table 1 features factual examples that demonstrate the proposed relationship. Furthermore, Table 1 includes data on the strength and measurability of examples of this association. The strength of examples was determined by exploring the presence of existing literature that supports the proposed connections. The measurability of examples corresponds to the authors' professional judgment about the ease with which the example could be systematically investigated.

RESULTS

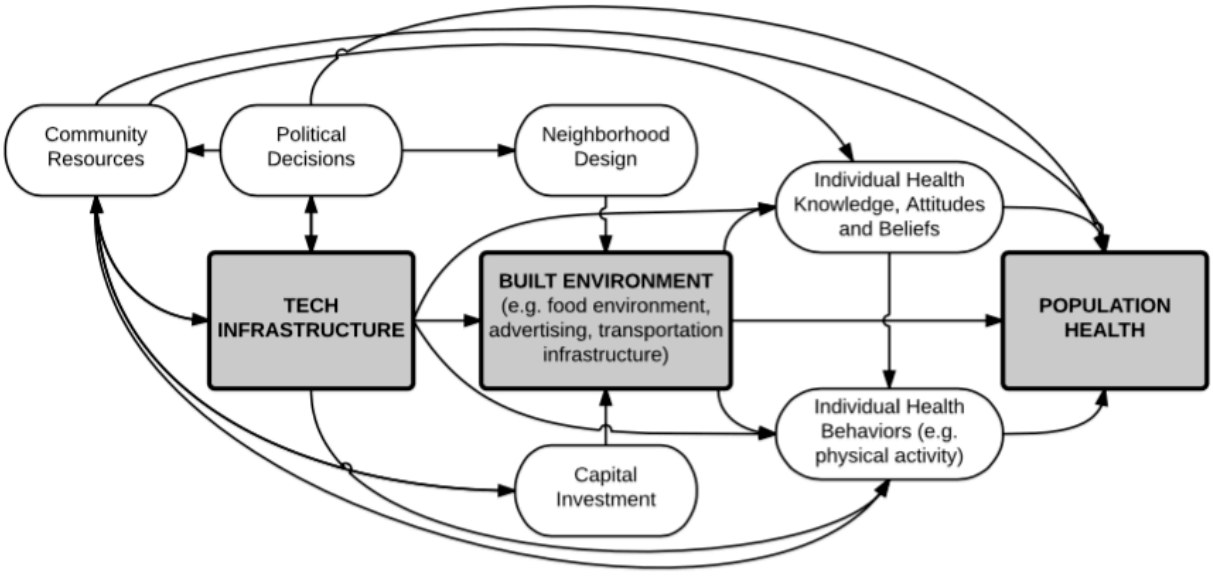

Figure 1. Technology, Health and the Built Environment

Figure 1 was adapted from Schultz and Northridge's (2004) framework (Appendix 1) linking the built environment to social determinants of health. Similar to the socioecological model of health, this framework identifies three primary domains encapsulating important determinants of health. Intermediate health determinants include environmental context such as the built environment and technological infrastructure (which is determined by technological innovation) can influence individual and population health via their impacts on macroscopic (i.e., natural environment, social institutions and inequalities) as well as microscopic factors such as health behaviors. To further elaborate, consider the following descriptions of the different domains of health determinants outlined by Schultz & Northridge (2004)

> 1) The macroscopic domain, which includes contextual factors such as the natural environment, socio-cultural institutions and societal norms,
> 2) The intermediate domain, which includes factors such as the built environment (e.g., transportation infrastructure, land use decisions and other factors related to social contextual factors such as community cohesion, and civic engagement) as well as political decisions that inform how resources are distributed within communities, and
> 3) The microscopic domain, which includes factors such as stressors related to the built and natural environments (e.g., exposure to pollutants, crime and poor discrimination), health behaviors (e.g., physical activity), social integration and social support. These factors are important precursors for health behaviors as well as other exposures related to individual and population level health outcomes.

These domains offer a useful framework for better conceptualizing the interconnections between environmental (i.e., natural and built) factors, health-related behaviors and population-level health outcomes (Schultz & Northridge, 2004). Better understanding the reciprocity between these domains is important for more deeply exploring factors that impact environment-related health disparities (such as technological innovations that can influence behavior and change health). This framework demonstrates the fact that the built and physical environments both represent important determinants of health. Changes in our technological infrastructure (which is established by digital advances) can impact health related behaviors as well as health outcomes through many different pathways. For example, access to more information about behavioral patterns may influence the likelihood that one will actually engage in health-promoting behaviors. On a larger scale, increased use and penetration of digital devices may promote political decision-making that further strengthens the technological and environmental infrastructure. This is relevant and important because the built environment and the technological infrastrucute both represent important intermediary determinants of health that can change health outcomes as well as the varied contexts in which health occurs. Indeed, Schultz and Northridge identify programmatic and policy interventions— factors that intersect the macroscopic and microscopic domains—as being distinctly poised to impact health outcomes (Schultz & Northridge, 2004).

Figure 1 demonstrates a proposed causal mechanism for how technological infrastructure modifies the relationship between the built environment and health-related behaviors. This model can be conceptualized as a lattice over a deconstructed Schultz and Northridge (2004) framework. This overlay permeates the macroscopic domain through built environment-related policy change and ultimately influences the context in which health occurs. Intermediary factors (i.e., transportation systems, public resources, zoning regulations, community investment and social context) influence and subsequently provoke direct and indirect changes at the macroscopic (e.g., socio-political context) and microscopic domains (e.g., health behavior).

Figure 1 acknowledges that the pathways informing health outcomes are dynamic, non-linear and inherently difficult to conceptualize. Though complex, it is nonetheless important to characterize and analyze the nature of these highly nuanced systems. Doing so will help researchers and decision makers to better identify key areas to target with policy and research interventions (Leischow & Milstein, 2006). Furthermore, deconstructing these complicated connections will lay the foundation for taking more comprehensive and ecological approaches to identifying the most impactful and sustainable domains to target (Leischow & Milstein, 2006; Bloom and Dees, 2008).

Table 1 offers factual examples that demonstrate the proposed mechanism in action. Table 1 introduces different aspects of the technological infrastructure (i.e., transportation technology, smartphone applications, and wearable technology) and provides examples of how these technologies can modify the relationship between the built environment and health behaviors in order to ultimately impact health. Transportation technologies (e.g., ride share smartphone applications, telecommuting, and transit trackers) in particular represent some of the most salient and quantifiable examples presented in Table 1 and are explored in greater detail below.

Measurability

While the impacts of the associations identified in this inquiry (See Table 1) are overwhelmingly positive, potential adverse health outcomes should also be considered. The widespread adoption of smartphones in both developed and developing contexts may favorably influence health by collecting useful health data that helps people to manage their weight, monitor physical activity levels and/or promote healthier behaviors. However, without proper disposal practices, these devices may contribute to substantial electronic waste in already vulnerable locales. In addition to being harmful to the environment, improper disposal of electronic waste may disproportionately affect vulnerable populations (Grant et al., 2013). In addition to this, another factor to consider is the fact lack of uniformity associated with the diffusion of innovation (i.e. digital divide) may, in fact, contribute to greater health disparities. Prior to making a recommendation to adopt (or fail to adopt) new technologies, it is essential to consider the potential intended and unintended associated consequences—both favorable and unfavorable.

Table 1 introduces examples for how technological innovations can (and do) influence health by modifying the relationship between the built environment and health behavior. There are both positive and negative health consequences to consider when exploring this effect. Table 1 includes information that describes our confidence in the ability to characterize these relationships using a "Measurability Score" from low (score =1) to high (score=3). Further researcher on this subject will inform the clarity with which we view and understand aspects of the technological, environmental and health relationship. For example, in a retrospective research study exploring public transportation smartphone applications, bus ridership, and transportation-related health outcomes, latency of health outcomes and other interfering variables (i.e., time of year, changes in diet and physical activity patterns/or) may make it difficult to determine directionality and causality. Furthermore, while it may be feasible to collect data on smartphone application downloads and even actual application use, slow developing health outcomes (such as heart disease stroke, and changes in weight or BMI) may complicate the ability to definitely claim that the smartphone application changed the health outcome of interest.

Among the various technologies reviewed in Table 1, the Transit Tracker section has high measurability. For example, it would be feasible to prospectively quantify health effects (i.e. physical activity, weight loss, body mass index) associated with the use of a smartphone transit tracker app such as OneBusAway, which is now available in six cities (www.onebusaway.org). A more involved mixed methods research study might explore directionality and strength of

associations between the aforementioned health outcomes and transit tracker use, transit tracker accuracy as well as public transportation ridership. Such a study might survey participants and ask about perceptions about how application use influenced behavior and other aspects related to transportation infrastructure (i.e., bus reliability and frequency as well traffic congestion).

The Telecommuting section of Table 1 also has high measurability. For example, it would be feasible to measure and characterize the association between telecommuting and automobile usage. Surveying people who telecommute and inquiring about transportation patterns on normal commuting versus telecommuting days could provide important and relevant information on this relationship. Furthermore, data could also be collected an explored on the ways people use the time that they would have otherwise spent commuting. Important factors to consider include accounting for self-report biases and how to best characterize how nonevents (i.e., not driving) influence health (i.e., reduced injuries and death related to vehicular collisions) as well as the built environment.

Similarly, the Walk Score section of Table 1 has strong measurability. For example, it would be feasible to design a study that compared neighborhood Walk Score with measures of physical and mental health (e.g., depression, physical activity, BMI). Indeed, higher neighborhood Walk Score has a demonstrated positive association with increased as well as more vigorous physical activity (Frank, 2006; Hirsch et al., 2013). It would also be feasible to investigate how an area's Walk Score relates to community resources, neighborhood design (i.e., presence and quality of green space, air quality, sidewalk quality) and measures of physical and mental health (Murray, 2011; Booth et al., 2013).

Scenarios

This section features short and fictitious scenarios that link health, technology and the built environment. Table 1 and Figure 1 both demonstrate the complexities of this relationship. Many of the implicated pathways can be opaque and otherwise difficult to conceptualize. These scenarios represent simple examples that are meant to assist in better envisioning these complex associations. The most compelling and promising (i.e., measurable) examples from Table 1 are included and explored using fictitious scenarios below.

Telecommuting

Klaus works a white-collar job where he telecommutes three days out of the week. With the time he saves, Klaus now prioritizes exercising and preparing meals at home. Working from home just a few couple of times each week helps remove a car from the road—if enough people do it this might help decrease injuries and fatalities related to vehicular collisions as well as the environmental impacts of traffic congestion.

Tracking Systems for Adolescent and Elder Drivers

Jeb observes his aging father's driving activity by wireless connecting the MOTOsafety Vehicle Tracking System in his father's car to his smartphone. Now Jeb receives real-time alerts if his father displays unsafe driving practices such as rapid acceleration or abrupt braking. The MOTOsafety device has given Jeb peace of mind and allows his father to maintain his independence. Jeb's smartphone seamlessly syncs with the MOTOsafety Vehicle technology to ensure that prompt action can be taken before undo risk is posed to his father or to those with whom he shares the road.

Walk Score

A couple looking to purchase a home now considers the Walk Score walkability score that is listed on the real estate website a big part of their decision making process. They would like to

live in an area that facilitates—rather than hinders—their ability to lead a healthy lifestyle. The most promising houses that they have visited were in safer areas, more aesthetically pleasing, conveniently located near desirable amenities (i.e., grocery stores, parks, outdoor farmer's markets) and had higher Walk Scores. In addition, more and more people value the active living associated with walkable neighborhoods. This has important implications for property value as well as neighborhood design.

Smartphone Applications: Reporting Hazardous Road Conditions
Christina recently used Pothole Alert 311—a smartphone application for reporting non-emergent issues like potholes and fallen trees—to alert appropriate officials about a malfunctioning traffic signal light in her neighborhood. With this prompt report, city officials were able to quickly resolve this issue before the evening rush hour. This helped prevent inconvenient and potentially dangerous driving conditions.

Smartphone Applications: Transit Trackers
Dissuaded by heavy traffic and expensive parking costs, Tara now uses the OneBusAway smartphone application to get to work and school. The closest bus stop is a short walk from her apartment but the bus is seldom on schedule. Knowing when to expect the bus helps Tara to better economize her time. Tara has also found that her bus experience and the application's accuracy have both improved as more people use it to plan their trips. Furthermore, increased use of transportation technologies such as OneBusAway may help further strengthen and improve transportation infrastructure which may, in turn, lead to increased demand for public transportation ridership as well as fewer drivers on the road.

Smartphone Applications: Rideshare
Dwayne uses the Uber smartphone application to get to work. Sharing a ride with coworkers using UberPool (which allows users to share the cost of their ride with others along the same route) removes several cars from the road, helps decrease traffic and reduces the stress he once felt about his commute. Fewer drivers on the road may help tackle issues related to transportation infrastructure (i.e., ballooning transportation infrastructure and roadway expansion).

Autonomous Vehicles
Subscriptions to autonomous vehicle services are becoming increasingly feasible and will represent a major advancement in car share technology. Although there are many unknown factors to consider before recommending widespread adoption, the mainstream use of autonomous vehicles may help reduce traffic congestion, decrease greenhouse gas emissions and improve health outcomes associated with car-related noise and environmental pollution. In addition, driverless cars may decrease collision-related injuries and deaths because the autonomous vehicle technology substantially reduces the likelihood of human error and distracted driving—the leading causes of vehicle-related injury and deaths (Singh, 2015; NHTSA, 2008).

CONCLUSIONS

Discussion
Changes in our technological infrastructure are driven by innovations that are introduced on a near-constant basis. Technological and digital advancements have the potential as well as the demonstrated capacity to meaningfully influence health and wellbeing by simplifying and streamlining healthy decision-making via environmental transformations. From real-time information about how to shop and eat smarter, to improved ability to identify safe and efficient routes to school and work, there are endless opportunities for leveraging these tools so that they

positively influence health behaviors. To this end, these technologies may inspire political and environmental changes that promote healthy behaviors and improve health.

The goal of this inquiry was to introduce and explore the ways in which digital advances influence health outcomes. This was achieved by engaging content experts, creating a causal framework that encapsulates the various inputs for this relationship and by highlighting factual instances of this effect. Perhaps more now than ever, societies are confronted with complex health related concerns such as eliminating health disparities and addressing health concerns associated with climate change. These issues demand dedicated and intentional solutions. Achieving a deeper and more comprehensive understanding of how health, the built environment and technology converge is an important step for catalyzing change. By leveraging emerging digital advancements, we can identify better solutions for addressing these obstacles, transforming patterns of behavior and improving health outcomes.

Limitations

Some of the limitations involved in this research include:

1. Unpredictable outcomes. There is inherent difficulty associated with identifying the causal pathways that link technology, the built environment and health behaviors.
2. Limited ability to assess the extent to which these technologies influence health. Further development on the proposed mechanism will help to better characterize and generalize the ways in which technological innovations impact health in diverse contexts.
3. Potential privacy concerns associated with collecting data on technology use. For example, data collected from smartphone application may be linked to other personal information such as contact lists (i.e., telephone numbers, email addresses and physical addresses) as well as location data.
4. This is an exploratory inquiry with much room for expansion. Additional ideas may have been obtained had more experts been interviewed.

Recommendations

Although difficult, it is possible to uncover useful information from strategic inquiries that explore how new technologies impact health. As these advancements emerge, an assessment of potential health implications will be critical for identifying high impact approaches to public health issues. A more comprehensive understanding of the available technologies as well as their impacts on health outcomes and environmental contexts is crucial for **a)** predicting positive and negative unintended consequences as new technologies are introduced and for **b)** intentionally creating environments that are more conducive to health and wellness. Technological advances can help planners, policymakers and legislators make more informed decisions related to neighborhood design. These decisions have important implications health related behaviors and, ultimately, population health.

Engaging experts with different areas of expertise will help to better and more comprehensively describe the association between changes in the technological landscape, built environment, and population health. More specifically, it is beneficial and important to incorporate a public health orientation in domains (e.g., transportation and technology) that are not traditionally (or even explicitly) health focused. A deeper understanding of the causal mechanisms that underscore this relationship will inform more intentional and impactful research as well as policy decisions that reduce rather than exacerbate health disparities. Therefore, early and consistent engagement from health experts is critical in community and technology design, implementation and review.

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Appendix 1: Schultz & Northridge Conceptual Model

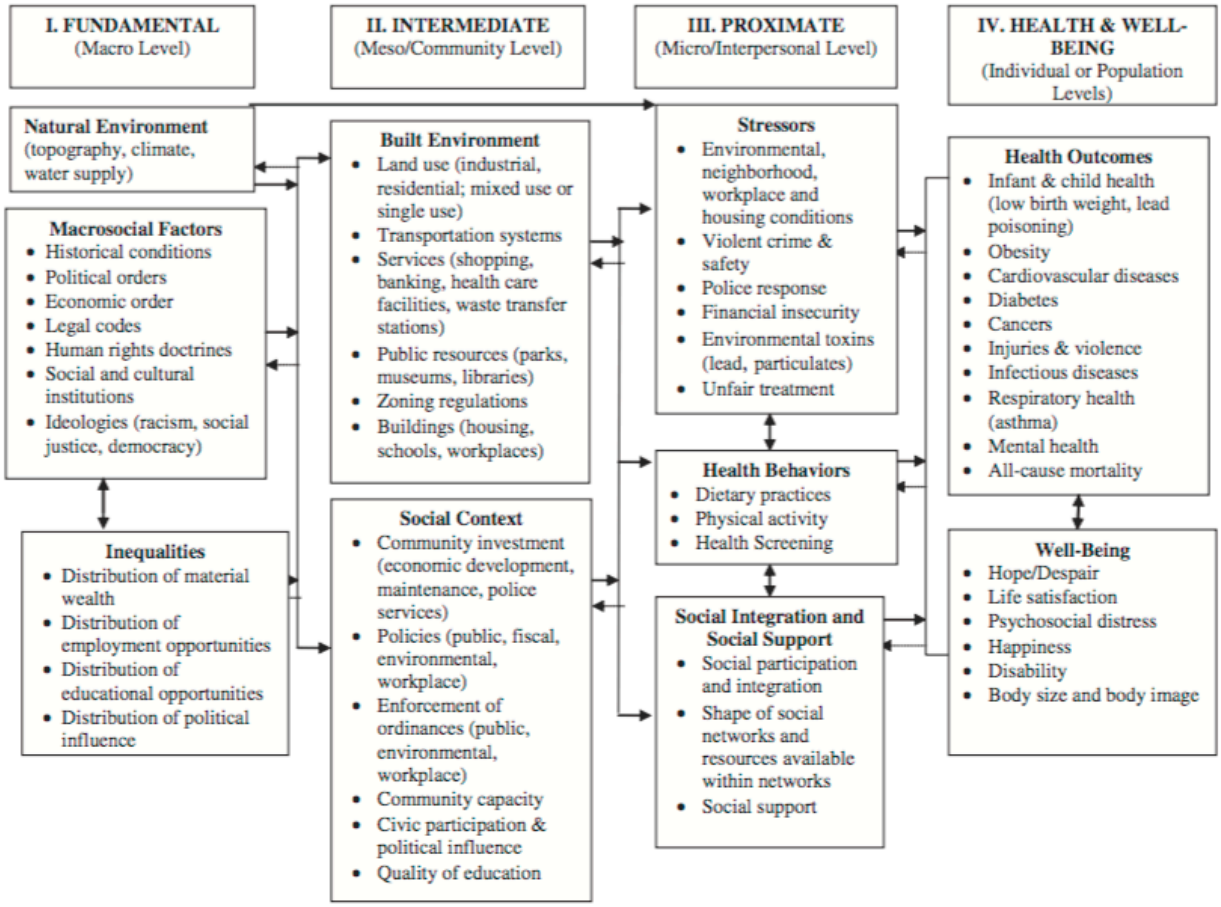

Figure 1. Social determinants of health and environmental health promotion.
NOTE: The model presented in Figure 1 is adapted from a conceptual model for understanding racial disparities in health that appears in Schulz et al.[1] In keeping with our emphasis here on social determinants of environmental health disparities, the model has been modified to specifically examine relationships between social inequalities, the built environment and social context, and environmental health disparities, drawing on Northridge and Sclar.[2]