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INTEGRATING HEALTH INTO BUILDINGS OF THE FUTURE

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Abstract

The health and wellbeing of building occupants should be a key priority in the design, building, and operation of new and existing buildings. Buildings can be designed, renovated, and constructed to promote healthy environments and behaviors and mitigate adverse health outcomes. This paper highlights health in terms of the relationship between occupants and buildings, as well as the relationship of buildings to the community. In the context of larger systems, smart buildings and green infrastructure strategies serve to support public health goals. At the level of the individual building, interventions that promote health can also enhance indoor environmental quality and provide opportunities for physical activity. Navigating the various programs that use metrics to measure a building's health impacts reveals that there are multiple co-benefits of a "healthy building," including those related to the economy, environment, society, transportation, planning, and energy efficiency.

BUILT ENVIRONMENT HEALTH IMPACTS

The built environment can promote healthy environments and behaviors, as well as mitigate adverse health outcomes. Air quality, social equity, community cohesion, physical safety, transportation choices, traffic-related crashes, water quality, access to healthy foods, physical activity levels, access to nature, and daylight levels all influence public health [1].

Physical activity promotion is one of many ways the built environment can support health. Physical activity can help prevent hypertension, stroke, non-insulin dependent diabetes, colon cancer, osteoarthritis, osteoporosis, and cardiovascular disease and can also help

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prevent obesity, which exacerbates many of these conditions [2]. The built environment can support physical activity by providing opportunities for active transportation, trips to nearby destinations, and access to green spaces and parks. Built environment interventions can be maximized when their multiple impacts (for example, in reducing energy use and creating cooler microclimates) are acknowledged and leveraged.

Globally, buildings account for between 20% and 40% of energy consumption in developed countries, exceeding contributions from the industrial and transportation sectors [3]. In the United States, commercial buildings and industrial facilities generate 45% of the nation's greenhouse gas emissions [4], which drive global anthropogenic climate change. These emissions come from not only building-level construction, materials, and energy use, but also from the level of building connectedness in the context of transportation and water systems, as well as at the scale of land use changes [5]. Therefore, buildings and the built environment stand to play an important role in climate change mitigation, as well as adaptation to changing climatic conditions, creating opportunities for co-benefits for public health [6].

Climate change is already affecting human health and wellbeing in the United States, and the negative health impacts of climate change are expected to increase in the future [7]. Climate change can modify existing health threats that are relevant to the built environment, such as urban heat islands, air pollution, and flooding. In particular, extreme heat events are increasing in both magnitude and duration [8]. Warming temperatures affect health in a variety of ways, with negative impacts on respiratory, cardiovascular, and neurological systems [9].

The design of buildings and neighborhoods affect outdoor surface temperature, indoor temperature, air quality, and water quality. Indoor conditions—including housing quality [10] and daylighting [11]—and access to green spaces and social spaces have important implications for both physical and mental health [12]. Built environment features impact water quality through the transport of pollutants into water, wastewater treatment, and water system infrastructure. Health impacts from exposure to chemical and biological water contamination range from neurological effects from lead to infectious diseases such as Legionnaires' disease.

Public health focuses on the population level. While it is relevant to evaluate the opportunities for positive and negative health impacts at the scale of the building, it is also necessary to evaluate health impacts at the population level at the scale of a city or community. Building managers and engineers can address problems and enhance health-promoting features for an individual building. Similarly, urban planners and developers can design systems, networks, and places that impact population-level health. Therefore, the purpose of this paper is to describe ways in which buildings and the built environment can impact health and to propose some possible solutions.

SMART BUILDINGS, SMART CITIES: A SYSTEMS-LEVEL BUILT ENVIRONMENT APPROACH

The built environment is more than a collection of buildings; rather, it encompasses the interconnectedness of buildings, transportation systems, infrastructure, and open space (to name a few elements) at the systems level. Buildings exist in relationship to their community and context, and, therefore, their effects on health extend to this level as well. In an article on bio-inspired intelligent urban environments, Maibritt Pederson Zari suggests broadening the definition of an intelligent building in the future to include buildings that are able to communicate with and respond to each other and the wider urban context [13]. Contextualizing individual smart buildings within smart cities is analogous to taking a community or population health approach, rather than focusing solely on individual-level health. In this way, the public health perspective necessitates systems-level thinking.

The authors of this paper propose that buildings of the future could explicitly incorporate scalable, interoperable "smart building to smart city" concepts that could positively affect individual and population health outcomes. These include physical features (traditional built environment) and informatics features—such as interconnected data collection, monitoring, and control—as well as actuation and response components. Together, these features could serve to enhance the built environment to reduce adverse health-related impacts and improve the overall health of building occupants and the community.

While there might be no widely agreed upon definition of a "smart building" [14], some definitions of smart buildings include the following features:

- Integrated and automated systems such as Building Automation and Energy Management Systems, fire and life safety, environmental conditions, security, and telecommunications;
- Information gathering and monitoring systems with data sharing and interoperability amongst systems, often in real time and with some "corrective action and reaction" capability;
- Sustainable and environmentally accountable location, materials selection, demolition, design, construction, and operations and management practices; and,
- Personalized or highly localized occupant amenity systems or features, in addition to those mentioned above, that support and integrate tenant health, convenience, comfort, and wellbeing into the building.

Table 1 lists features gathered from health and built environment research, as well as informatics features distilled from smart building and smart city concepts. Planners, landscape architects, developers, architects, engineers, building occupants, and other stakeholders could intentionally develop, coordinate, and implement these features to link, leverage, and aggregate smart buildings into smart neighborhoods and smart cities [15–22].

As the building blocks of smart cities, future smart buildings could incorporate these features and functions in aggregate to form neighborhoods, communities, districts, and other critical components of urban form. At these aggregated levels, the appropriate organizations, such as public health agencies and utilities and service agencies, could collect relevant data to inform action. For example, the smart city initiatives described by Albino et al. [23] might benefit from building-level data input in addition to utility-level and mobile source data collection. In Seattle, examples of these smart city initiatives include the following: Smart Grid, Automated Metering Infrastructure, Drainage and Waste Water System, Rain Watch Program, Supervisory Control, and Data Acquisition [23].

Key features of these systems have been shown to support activities and attitudes that contribute to positive health outcomes, particularly with respect to physical activity (e.g., walking, biking, and active recreation) and mental and emotional wellbeing [15–20, 22, 24]. Smart buildings systems could collect data (with provisions for confidentiality) on occupant physical activity use of stairways, on-site wellness or fitness centers, and sidewalks.

A building's location and context within an interconnected smart city has implications for the way people access and travel to and from it. A number of design strategies can promote physical activity through walking, bicycling, and active transportation [25–27]. Community design strategies can promote safety by protecting pedestrians with sidewalks and safe street crossings, buffers between pedestrians and vehicles, and traffic-calming measures, as well as by using lighting and natural surveillance through "eyes on the street" as crime prevention approaches [25, 28]. By making buildings easily accessible, providing connections to pedestrian and bicycling systems (similar to connections between parking areas and roads), installing clear signage, and promoting a density of nearby destinations, built environment design can maximize the convenience and comfort of walking and biking [25].

Furthermore, the scale of a building can be optimized for the street level to encourage more pedestrian behavior [25], ensuring that sidewalks and paths are wide enough to allow people to walk next to each other and demonstrating pedestrian scale through structural building articulation. Structural features that support biking include visible bike storage, covered bike parking, lockers, and showers. A review of the literature found strong evidence for multiple benefits towards physical health, environmental sustainability, and economic benefits for park presence and proximity, greenery, street scale pedestrian design, accessibility and street connectivity, and building design [29].

BUILT ENVIRONMENT SOLUTIONS: GREEN INFRASTRUCTURE

One approach to built environment that incorporates this interconnectedness between community and context is "green infrastructure," which is defined as "a systematically managed network of open space that conserves ecosystems and provides associated benefits to human populations. This network includes wildlife habitat, water management, air and water quality, climate mitigation, urban forestry, urban agriculture, and the public realm infrastructure needed to support healthy lifestyles such as parks, sidewalks, trails, and street trees" [30]. Green infrastructure presents a way to leverage co-benefits, ranging from the mitigation of urban heat islands to increased opportunities for physical activity. This is accomplished by designing infrastructure projects to address multiple community goals. Furthermore, detention areas can be designed for multiple uses. These areas can incorporate water quality best management practices for treating runoff close to its source and can be adapted to many different applications, such as rooftops, sports fields, recessed plazas, and parking lots [31].

Establishing buffers for sensitive lands might create opportunities for trails and picnic areas while facilitating natural processes [29]. Examples of green infrastructure projects that create synergies include designating spaces for walking, biking, open play lawns, or urban agriculture in areas with other purposes such as detention areas or flood plain zones [29]. Such approaches support the leveraging of community resources.

While exposed paved surfaces and other heat-trapping and reflecting materials exacerbate the urban heat island effect, the implementation of green infrastructure adaptation strategies, such as cool roofs, public greening, and increasing the albedo of paved surfaces, can help to lower temperatures and protect human health [32]. In particular, the benefits of shade and canopy trees extend to reducing energy consumption in surrounding buildings [30, 33–35], as well as providing additional environmental health benefits such as filtering air pollution and reducing stormwater runoff [30]. Implementation of these interventions should be targeted to susceptible populations, as some communities and geographic locations are particularly vulnerable to heat morbidity and mortality as temperatures increase [36].

Studies have found that access to green space might have significant health benefits that include reduced stress, reduced rate of mortality, improved cognitive function and mental health [37, 38], positive influence on recovery from surgery [39], increased opportunities for exercise, improved symptoms of attention deficit disorder in children [40–42], and a reduction of the effect of poverty on all-cause mortality [43–46].

Water management is an essential part of organizing these integrated systems. Green infrastructure interventions serve to diminish the amount and concentration of water pollutants by decreasing the volume of runoff water entering the water system, as well as by filtering pollutants out or degrading them (biologically or chemically) [47]. This prevents concentration of water volume that can lead to flooding and combined sewer overflows [48], which have been shown to be associated with waterborne disease outbreaks [47, 49]. Green infrastructure may reduce the impact of large areas covered with impervious surfaces; such areas not only prevent groundwater recharge but also facilitate the movement of pollutants into the water system [48].

BUILT ENVIRONMENT SOLUTIONS: BUILDING LEVEL

Within an individual building, occupant health can be promoted through a number of means, including reducing potentially harmful exposures and promoting physical activity and mental health.

1. Indoor Environmental Quality

Indoor environmental quality (IEQ) relates to the experience of the building’s occupants and includes air quality, ventilation, thermal conditions, lighting, and acoustics [50, 51].

However, this paper will focus on a few of these variables as they relate to smart buildings; namely, non-infectious agents, ventilation, thermal conditions, and lighting.

A broad-based expert workgroup of housing and health professionals in the National Healthy Homes Training Center and Network, funded by the Centers for Disease Control and Prevention (CDC), developed the National Center for Healthy Housing's seven healthy homes principles, which "provide for keeping homes dry, clean, well-ventilated, pest-free, free from contaminants, safe, and well-maintained" [52]. Select examples include:

- Keep It Dry: Install drains or catch pans to capture overflow or leaks from conventional hot water heaters, air conditioners, or dehumidifiers;
- Keep It Clean: Install smooth floors (as opposed to carpet) and central vacuuming systems;
- Keep It Well Ventilated: Prevent short-cycling heating or air conditioning and ventilation before occupancy;
- Keep It Safe: Ensure smoke detectors are functional and install grab bars for housing with occupants over 55 years of age;
- Keep It Free of Contaminants: Use low volatile organic compounds (VOC) products;
- Keep It Pest Free: Use rodent-proof materials and low-VOC caulk to seal wall, floor, and joint penetrations, if appropriate; and,
- Keep It Well Maintained: Provide a homeowner's manual and a walkthrough of the home with the builder's maintenance instructions for the homeowner [52].

Air quality is a substantial component of IEQ, and building-level interventions have been shown to improve air quality and related health effects. Indoor pollutant concentrations are influenced not only by the source and attributes of the pollutant, but also by the characteristics of buildings and human behaviors [53]. Building-level design and interventions can mitigate the concentrations of and occupants' exposure to indoor air pollutants, which pose threats to human health, especially those resulting from environmental tobacco smoke, outdoor particulate matter (PM), radon, volatile organic compounds (VOCs), and semivolatile organic compounds (SVOCs).

Smoking increases indoor ultrafine particulate matter (PM), particularly PM 2.5 and hazardous air pollutants [53–55]. The decrease in indoor smoking has contributed to decreased exposures for nonsmokers [53, 56].

In addition, because outdoor particulate matter constitutes a substantial proportion of indoor particulate matter [57], buildings should be equipped with proper filtration systems. Well-maintained filters in mechanical ventilation systems (not exhaust-only systems) effectively remove outdoor particles [53, 58]. In comparing green affordable housing with conventional affordable housing, one study found that green homes had significantly lower levels of PM 2.5, nitrogen dioxide, and nicotine, despite a lower air exchange rate. However, carbon dioxide concentrations were elevated in the green homes [59, 60]. Air exchange rate can be controlled through ventilation, which is discussed later in this section.

Radon is an important risk factor for lung cancer. The sources of exposure in a building are from underground, primarily from infiltration from soil gas, but also from building materials and tap water [53, 61]. Radon exposure depends upon indoor concentrations and the nature of air filtration and movement; thus, ventilation must be designed to effectively remove radon from indoor air [53, 62].

While both volatile organic compounds (VOCs) and semivolatile organic compounds (SVOCs) have the potential to be present in the gas phase, VOCs are predominantly in this phase, and SVOCs are predominantly in the condensed phase. Many of these chemicals are hazardous air pollutants (HAPs), which means these pollutants can cause cancer or other serious health effects, such as birth defects or adverse environmental or ecological effects [63]. VOC exposure can lead to respiratory symptoms, including asthma, allergies, and sick-building syndrome [53].

Newly constructed or renovated buildings have higher levels of VOCs and SVOCs, because these compounds are highly concentrated in materials such as paints, flooring installation materials, and adhesives [53, 64]. Other sources identified as health risk factors in a review of the epidemiological literature include formaldehyde and formaldehyde-emitting particleboard, phthalate plasticizers, plastic materials, and recent painting [53, 65]. Ventilation and occupant behaviors are important mechanisms to mitigate VOC and SVOC exposure, as well as the selection of materials and products with lower emissions of these chemicals [53].

The 2004 Institute of Medicine report, “Damp Indoor Spaces and Health,” found sufficient evidence that damp indoor spaces and the presence of mold are associated with upper respiratory tract (nasal and throat) symptoms, and cough, wheeze, and asthma symptoms in sensitized asthmatic people. This report concluded that indoor dampness can lead to mold and bacteria growth and benefit house dust mites, while excess moisture can promote the release of toxic chemicals from building materials and furnishings [66].

The expected increase of the duration, frequency, and intensity of extreme weather conditions due to climate change [8] might compromise building envelopes, which can promote the intrusion of water into buildings, thereby encouraging the growth of fungi and bacteria [53]. Furthermore, this dampness and growth might cause the decay or corrosion of building materials, leading to chemical off-gassing [53]. The chemicals and products used to combat fungal growth must also be considered for their unintended consequences on human health [53].

Air conditioning provides relief from increasing ambient temperatures and reduces exposure to some outdoor air pollutants; however, heating, ventilating, and air conditioning (HVAC) systems that are not maintained or cleaned can negatively impact building occupants’ health by circulating contaminants [53]. Furthermore, increased use of air conditioning might feed into the urban heat island effect from the heat generated from running the system [36], and the use of fossil fuel power generation to provide electricity for air conditioners contributes to the greenhouse effect. The challenges posed by limiting the exchange of indoor air with outdoor air, known as the air exchange rate (AER), demonstrate a further need for proper HVAC systems. If weatherization measures continue to limit the AER [67], then some indoor pollutants might become concentrated, even if outdoor pollutants are prevented from reaching building occupants inside [52, 53].

An intervention which offers mediation for some of the challenges posed by HVAC systems is the use of shade trees to shield buildings from summer and evening heat gain [68]. Using vegetation for shading has been shown to decrease temperatures substantially; indoor temperatures have decreased up to 20°F (11°C) in residential settings, and the outdoor microclimate immediately surrounding the vegetation has been shown to decrease by as much as 9°F (5°C) [69]. These effects have yielded decreased energy demand and savings [33].

Moreover, daylighting—which has been defined as “the active and controlled use of natural light for building illumination” [11]—can decrease energy demand for artificial lighting [70] and reduce heat loss [71], in addition to reducing disruptions to occupants’ circadian rhythms [72] and improving occupant productivity and mental health [73]. Because current state of the art technology can now accommodate building-specific considerations [71], buildings of the future might further enhance these benefits.

IEQ has been shown to be associated with a range of health impacts, including allergies, respiratory symptoms and asthma, mental health, and overall health. IEQ interventions aimed at reducing asthma severity include air filters [74, 75], pest management [76], and education and environmental modification [77–80]. Studies comparing health effects before and after green housing interventions found reductions in sick building syndrome and respiratory symptoms, including asthma, emphysema, hay fever, sinusitis, chronic bronchitis [59, 60, 81, 82], and allergen levels, as well as increased self-reported general health status [83]. A study by Amanjeet Singh and colleagues showed that in addition to these respiratory health improvements, IEQ interventions can benefit mental health, as measured by self-reported productivity, stress, and perceived time affected by depression [84].

The studies’ authors described several limitations, which included relatively small sample sizes [60, 82], reliance on self-reporting and participant recall [82–84], and potential seasonality effects and the Hawthorne effect (the phenomenon of participants altering their behavior due to their awareness of being observed [84]). The strengths of some of the studies included quantitative environmental measurements, repeated measures, and comprehensive home assessment in order to adjust for potential confounders. Even when Hawthorne effect might have occurred, the results were in an anticipated positive direction for the intervention group. After weighing the limitations and strengths of intervention studies and taking into consideration the strong associations between poor IEQ and adverse health reported in observational studies, it is concluded that improved IEQ can be used to benefit human health.

Interventions that enhance IEQ have been demonstrated to promote occupants’ health, such as reducing asthma. A quasi-experimental study comparing two groups of low-income children and adolescents showed that those who moved into a home with "moisture-reduction features, enhanced ventilation systems, and materials that minimized dust and off-gassing…experienced large decreases in asthma morbidity and trigger exposure" as compared to the control group [85]. Decreased asthma morbidity was shown by increases in asthma-symptom-free days and decreased proportion of residents with an urgent asthma-related clinical visit in the previous three months [85]. A study by Meryl D. Colton and her colleagues found that residents of green low-income housing units showed improvements in sick building syndrome symptoms and asthma-related morbidity (measured as asthma symptoms, asthma attacks, hospital visits, and asthma-related school absences), as compared to residents in conventional low-income housing units [86]. Though there are many risks present in the indoor environment, using best IEQ practices effectively enhances health.

2. Smart building aspects

While advanced technologies and green design elements in smart buildings demonstrate a number of benefits [87], these technologies could be further developed in order to monitor health-related exposures and outcomes. A 2014 survey by McGraw Hill Construction and the American Institute of Architects indicated that green building firms have increased their efforts to address occupant health through design and construction [88], demonstrating builders' growing interest in this approach. The emergence of health connected to building design has historical roots: public health has improved as new building technologies were integrated into building materials, designs, and services (e.g., sanitation, occupational health, water treatment, fire safety, indoor air controls, reduction in lead-based paints, integrated pest management, healthy homes, etc.).

The future direction of smart buildings can include health at the forefront by enhancing the current relationship between buildings and their occupants [89]. However, occupants should be empowered to understand and overwrite automated smart building systems to fully capture the benefits of these relationships. Adding new forecasting elements, potentially through the Internet of Things (IoT) and micro-sensors, can help adapt a building to meet the needs of individual occupants in real time [89]. In fact, CISCO estimates that by 2020 there will be more than 50 billion networked devices connected to the internet, with roughly 83% comprised of wearable technology, appliances, and sensors [90]. The Royal Academy of Engineers is beginning to address this gap by creating stakeholder engagement with designers and builders to enhance the design of future buildings with open source feedback loops [91]. By institutionalizing this type of collaboration, smart buildings of the future can incorporate health as a cornerstone of their innovation.

3. Opportunities for physical activity

One way to promote physical activity throughout the day is by encouraging stairwell usage. Research shows that design features such as attractive aesthetic qualities (e.g., windows, artwork), point-of-use prompts and signage, and visibility and accessibility of stairwells promote stair usage [92–95].

4. Sustainability practices and strategies

Sustainability serves as a theme underlying each consideration made for buildings of the future, particularly with respect to both energy usage and preparations for the impacts of climate change. By defining comprehensive and integrated strategies for sustainability, public health will benefit in the long term. These sustainability practices and strategies, as summarized in Table 2, should target efficiency, source, and consumption of energy; waste diversion and reduction; water conservation; adaptation and resilience measures; and source, production, and health effects of materials [90, 91, 96–100].

The healthy building standards, metrics, and programs in Table 2 include several standards that differ in terms of energy targets. For example, the Living Building Challenge emphasizes net-zero status, while the focus of Leadership in Energy and Environmental Design (LEED) is on energy use reductions and ENERGY STAR compliance. Considerations for waste diversion and reduction, as well as water conservation, should be integrated into the planning phase of buildings. Furthermore, sustainability goals often prohibit the use of "red list substances"—such as asbestos, bisphenol A (BPA), formaldehyde, mercury, lead, chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs), cadmium, polychlorinated biphenyls (PCBs), perfluorinated compounds (PFCs), and phthalates—because of the threat they pose to human and ecological health [85].

HEALTHY BUILDING STANDARDS, METRICS, AND PROGRAMS

The various programs that use metrics to measure a building's health impacts also include consideration for impacts to the economy, environment, social cohesion, transportation, planning, and energy efficiency, thereby revealing multiple co-benefits of a "healthy building." Table 2 highlights a select number of programs, standards, and challenges related to buildings, sustainability, and health. LEED, for example, provides a number of measures and metrics for buildings aspects discussed throughout this paper, including: considering location and transportation (e.g., providing for bicycle facilities, access to quality transit), optimizing energy performance, responsibly sourcing raw materials, enhancing indoor air quality, and daylighting [101]. In order to integrate health into building and built environment projects, Table 3 presents a variety of toolkits and tools that practitioners can use to incorporate health into their work.

CONCLUSION

By identifying and implementing strategies to create smart, green, and healthy buildings, we can ensure that our cities of the future will emphasize public health and be prepared for the effects of climate change. Professionals responsible for designing, planning, building, engineering, and managing buildings contribute to public health impacts through their work. By embracing strategies that prioritize public health, building professionals can make a contribution to society that lasts beyond the life of the building.

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APPENDIX

Table 1

Physical and informatics features: Building and aggregate levels

Physical Features – Building & Aggregate Levels	Informatics Features – Building & Aggregate Levels
• Safe, accessible parks and green spaces and restoration and retention of urban canopy to encourage physical activity and support "placemaking" and community cohesion	• Resource efficiency and conservation (fuel cells, solar, water harvesting and conservation, area-level LED applications, wind turbines, smart and micro-grid applications, block-level "cool roof fields," etc.)
• Safe, accessible transit and an array of transportation choices to encourage physical	• Near field communication (NFC) technology and similar for real-time,

Physical Features – Building & Aggregate Levels	Informatics Features – Building & Aggregate Levels
activity and transportation system efficiency, and increase access and mobility to enhance social equity	broad coverage and individual connectivity to smart building and smart city applications
• Access to healthy foods, locally-produced foods, urban “infill” farming, “vertical farming,” and “roof farming”	• Real-time parking applications (“my garage is empty and the neighboring building has a surge need!”)
• Accessible school routes that promote physical activity and possible inclusion of educational space in large developments	• Real-time security surveillance systems (including various cameras and other devices) for access control and incident response
• Provision of thoughtful street-scale features such as sidewalks, bicycle facilities, aesthetic treatment, incorporation of street trees, street furniture, public/community space, and green infrastructure to increase physical activity	• Transportation sensors for real-time signal optimization, real-time parking management, Smart Car management, pedestrian and bicycle safety and routing, and incident response
• Enhance streets, particularly multi-modal concepts, using a “Complete Streets” approach, including grid restoration and increased connectivity	
• Increased but appropriate density, compact urban form, mixed use approach, and inclusion of affordable housing	• Peak-off peak usage and smart meters (water, power, etc.) to enable scalable smart grid and micro-grids
• Aesthetic, contextual site planning and design to reinforce a sense of place and community cohesion, particularly in “gentrifying” established communities	• Smart systems to promote more efficient urban planning and development to achieve healthy community design objectives and community participation
• Control, avoid, or abate pollution and noxious uses through careful site planning, brownfield and greyfield redevelopment, and modernization or recommissioning of existing buildings and infrastructure	• Real-time, linked, interoperable building (internal and external) sensors to monitor and report air and water quality to utilities and public health systems for tracking and intervention (versus reaction)

Table 2

Programs that use metrics to measure health impacts of buildings

Standard/Challenge	Description and Aims	Creating/Sponsoring Organization
Facility Innovations Toward Wellness Environment Leadership (FITWEL)	• “Voluntary commercial building certification program” including criteria for location, building access, outdoor spaces, entrances and ground floor, stairwells, indoor environment, workspaces, shared spaces, water supply, cafeterias and prepared food retail, vending machines and snack bars, emergency procedures [100]	Launched by the Center for Active Design and designed by a project team consisting of subject matter experts at General Services Administration (GSA), partnered with the Centers for Disease Control and Prevention (CDC) and the New York City’s Active Design Program and Department of Health (NYC)

Standard/Challenge	Description and Aims	Creating/Sponsoring Organization
Leadership in Energy and Environmental Design (LEED)	• Criteria include considerations for site, energy, water, materials and indoor air quality • Includes all building types and all phases of development • Levels of certification: Certified, Silver, Gold and Platinum • Programs for professionals: Accredited Professional (AP) and Green Associate [98, 99]	U.S. Green Building Council Third-party certified by Green Business Certification Inc. (GBCI)
WELL Building Standard	• An evidence-based system for "measuring, certifying, and monitoring" the performance of building features "that impact human health and wellbeing, through air, water, nourishment, light, fitness, comfort and mind" [97]	International WELL Building Institute™ (IWBI) Third-party certified by Green Business Certification Inc. (GBCI)
Living Building Challenge (LBC)	• "…building certification program, advocacy tool, and philosophy that defines the most advanced measure of sustainability in the built environment possible today and acts to rapidly diminish the gap between current limits and the end-game positive solutions we seek." [90] • Seven performance categories called "Petals:" Place, Water, Energy, Health & Happiness, Materials, Equity, and Beauty • Includes all building types and all phases of development [90]	Cascadia Green Building Council (a chapter of both the US Green Building Council and Canada Green Building Council), which created the International Living Building Institute to oversee LBC
Better Building Challenge (BBC)	• "…a broad, multi-strategy initiative aiming to improve the energy use of our nation's commercial, industrial, residential, and public buildings by 20% over 10 years" [91]	U.S. Department of Energy Launched by President Barack Obama in 2011
Atlanta Better Building Challenge (ABBC)	• A local program based in Atlanta with the goal of having "a 20 percent energy and water reduction by 2020" [96]	City of Atlanta, alongside with Southface (technical partner), Central Atlanta Progress, Midtown Alliance, and Livable Buckhead

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Table 3

Toolkits and tools for buildings and public health

Health Impact Assessments (HIAs) CDC Healthy Places	• A process that helps evaluate the potential health effects of a plan, project or policy before it is built or implemented. • Can provide recommendations to increase positive health outcomes and minimize adverse health outcomes. • Brings potential public health impacts and considerations to the decision-making process for plans, projects, and policies that fall outside the traditional public health arenas, such as transportation and land use. [102]
Urban Land Institute (ULI)'s *Building Healthy Places Toolkit: Strategies for Enhancing Health in the Built Environment*	• 21 evidence-based recommendations for promoting health at the building or project scale for real estate developments in three categories: 1) physical activity; 2) healthy food and drinking water; and 3) healthy environment and social wellbeing [103]
CDC Healthy Community Design Checklist Toolkit	• The checklist covers various topics, including: active living, food choices, transportation choices, public safety, social cohesion, social equity, and environmental health • Helps identify community-level health issues by providing health data and tools to create a "snapshot" of a community [104]
STAR Community Rating System	• Created by and for local governments • Helps communities "identify, validate, and support implementation of best practices to improve sustainable community conditions" [99]
Report to NIST on the Smart Grid Interoperability Standards Roadmap	• Describes the current status, issues, and priorities for developing and integrating interoperability standards • Explains "the high-level architecture for the smart grid including a conceptual model, architectural principles and methods and cyber security strategies" [105]
International Facility Management Association (IFMA) documents	• How-To Guides are available for a number of topics, including: waste stream management, carbon footprint, US government policy impacts, commissioning existing buildings, global green cleaning, data centers, green building rating systems, landscaping, water, lighting, no cost/low cost, food service, and the Environmental Protection Agency (EPA)'s ENERGY STAR® portfolio manager [98] • Can access the full Knowledge Library with an account