A scoping review of simulation modeling in built environment and physical activity research: Current status, gaps, and future directions for improving translation

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ABSTRACT

Existing reviews have suggested that simulation studies of physical activity and environments are an emerging area, but none have explored findings in this area systematically. We used a scoping review framework to assess the use of simulation modeling to inform decision-making about built environment influences on physical activity. A systematic literature search was conducted in multiple databases in January 2018. Sixteen articles met the inclusion criteria. The studies evaluated interventions and features that were related to neighborhood safety (crime or traffic), active transportation, land use design, and walking and biking infrastructure. All of the studies focused on urban areas and most considered heterogeneity of outcomes based on local context. The majority of studies (70%) did not appear to have engaged or been used by practitioners or policy-makers to inform real-world decisions.

There has been a growth of simulation modeling studies, but there remain gaps. The studies evaluated built environment interventions that have been recommended by expert panels, but more were of interventions related to active transportation; few considered recommended interventions to support recreational activity. Furthermore, studies have all focused on urban settings and there is a need to consider non-urban settings and how heterogeneity could reduce or exacerbate health disparities. More work to involve and evaluate practices for engaging stakeholders in model development and interpretation is also needed to overcome the translation of simulation research to practice gap, and realize its potential impact on the built environment and physical activity.

1. Introduction

Improving physical activity is a major public health challenge for the developed world. Despite improvements in the past decade, recent data indicates that approximately one-fourth (26.9%) of adults engage in no leisure time activity and about half (47.4%) do not meet the minimum recommendations for minutes/week of moderate to vigorous physical activity (Centers for Disease Control and Prevention, 2017). High proportions of adolescent youth (72.9%) are also failing to meet recommendations and this percent has not meaningfully improved since 2011 (Centers for Disease Control and Prevention, 2017). These low rates of physical activity have contributed to the epidemic of obesity and related poorer health outcomes (Ladabaum et al., 2014; Church and Martin, 2018). Of the many factors that influence physical activity, our built environment has received attention in the past two decades of research (Ding and Gebel, 2012). In public health research, the built environment encompasses the structures (e.g., parks, buildings) and systems (e.g., public transportation) that provide the spaces and places where humans live, work, and socialize. There are a variety of built environment elements including land-use patterns, small and large architectural and natural features, and facilities and services that link one location to another that shape access to and opportunities for physical activity (Brownson et al., 2009). Disciplines related to the built environment, such as urban development and transportation planning, are now observed as important players in efforts to improve environments that promote physical activity.

Hundreds of primary studies and dozens of reviews have been published about built environment and physical activity research (Ding

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and Gebel, 2012; Gebel et al., 2015). Factors such as the availability of sidewalks and recreation facilities, traffic safety, and active transportation have been studied and shown to be associated with physical activity (Ferdinand et al., 2012). Based on a review of the evidence, the U.S. Preventive Services Task Force recommends combining transportation system with land use and environmental design interventions to increase physical activity (Community Preventative Services Task Force, 2016). Transportation interventions include improving street connectivity, sidewalk/trail, bicycle, and public transit infrastructure. Land use and environmental design interventions include policies or projects that increase the diversity and proximity of work and recreation destinations, residential density, and access to parks and recreational facilities.

Emerging evidence has been met with a policy response. In addition to the U.S. Preventive Services Task Force (Community Preventative Services Task Force, 2016), the National Physical Activity Plan and other expert panels (Board of Directors of the National Physical Activity Plan Alliance, 2016; Williams, 2007; Schilling et al., 2009) have recommended a variety of environmental strategies to increase physical activity. Architects, designers, and public health practitioners are guided to consider strategies that address issues of safety, accessibility, convenience, and appeal of spaces for physical activity (Board of Directors of the National Physical Activity Plan Alliance, 2016). For any given community, however, it is a challenge to plan and implement the strategies because there are many heterogeneous and interconnected factors to consider. For example, there is considerable heterogeneity in land-use patterns and neighborhood demographics across communities, and interconnections between the built environment and factors such as social norms may also influence physical activity decisions. These heterogeneous and interconnected factors create an implementation challenge since various active design strategies will likely result in differential outcomes across communities and individuals.

Computational simulation modeling approaches have been of increased interest to help planners investigate how different policies and interventions may impact complex health problems (Galea et al., 2009; Luke and Stamatakis, 2012). In general terms, a simulation model is a digital prototype that is used to study the behavior of an actual or theoretical system. There are many types of simulation models. Some models are relatively simple such as regression-based forecasting models that project past trends into the future. These models are of less value for complex issues where it is important to understand and simulate mechanisms of influence that may change over time. Advances in technology have led to types of simulation models such as microsimulation, agent based, and system dynamics models that are highly relevant for built environment planning because they account for heterogeneous and interconnected factors. These types of advanced simulation models also provide an artificial laboratory to study effects in the context of complex factors of influence and guide decisions that are often time-intensive and costly (Auchincloss and Diez Roux, 2008).

For many years, simulation modeling has been used in urban and environmental planning as an approach to guide decision-making (Batty, 2008). Models such as UrbanSIM and SLEUTH have been used by many localities to plan for and address issues such as traffic congestion (de Palma et al., 2007a,b; Waddell et al., 2007; Waddell and Nourzad, 2002; Waddell, 2000, 2002) and urban land use (Clarke et al., 1997; Jantz et al., 2004). The SLEUTH model began as a cellular automata model for simulating wildfire spread and behavior (Clarke et al., 1994). The name, SLEUTH, is derived from the acronym of the input requirements of the model, including Slope, Land cover, Exclusion, Urbanization, Transportation, and Hillshade. Over the last 25 years, SLEUTH has become one the most popular simulation models of urban growth and land use change (Chaudhuri and Clarke, 2013). UrbanSim is a land use modeling system developed in the early 2000s (Waddell, 2002) that approaches urban growth simulation by integrating an external travel model to microsimulations of demographic change, urban land use, and environmental impacts. UrbanSim was designed to explicitly address the strong interactions between transportation and land use decisions, and the role of federal transportation and environmental legislation, and the impacts of state growth management programs (Waddell et al., 2003).

In contrast to urban planning, simulation modeling for chronic disease and physical activity is a relatively new, but growing area of research. There are two existing systematic reviews (one in 2013 and one in 2015) of simulation modeling related to chronic disease and obesity (Skinner and Foster, 2013; Nianogo and Arah, 2015). Both reviews indicated a growth of studies that highlighted the appropriateness of the method to study complex phenomena, but also highlighted gaps such as the limited incorporation of specific intervention effects and a lack of clear descriptions of how relatively simple models captured complex phenomena. The existing reviews also suggested that physical activity and environments were an emerging area of study, but did not explore the specific findings within this area at a deeper level.

The purpose of this study is to fill in this critical gap and explore the state of the science of simulation modeling specifically for understanding built environment influences on physical activity. In this scoping review, we identify research that has drawn on simulation modeling to examine built environment influences on physical activity and critically analyze the aims, content, and utility of the work. Our goal is to assess the research strengths and gaps in this area to inform key recommendations for future research.

2. Methods

We followed Arksy & O'Malley's (2005) (Arksey and O'Malley, 2005) and Levac et al.'s (2010) (Levac et al., 2010) scoping review frameworks to examine the extent and nature of research on simulation modeling for built environment planning to improve physical activity. We followed six major steps: 1) identifying the research question; 2) identifying relevant studies; 3) selecting studies; 4) charting the data; 5) collating, summarizing, and reporting the results; and 6) consultation.

2.1. Identifying the research question

Disaggregating the broad question stated in the introduction, our primary research questions were defined as: (1) What is the extent, range and nature of research that has used simulation modeling to examine built environment effects on physical activity? (2) What is the potential for using the simulation models to help policy-makers and practitioners make decisions about implementation of built environment intervention strategies?

2.2. Identifying relevant studies

A search strategy was developed with an information specialist to conduct a comprehensive literature search in January 2018 in the following databases: PubMed, GEOBASE, BIOSIS Citation Index, AGRICOLA, CINAHL and Scopus (which includes EMBASE and MEDLINE), SPORTDiscus, Web of Science, and ProQuest Health & Medicine. The search included articles in English published between 1969 (year of the oldest article retrieved) and 2018. The following are examples of keywords and Boolean operators used: (“active travel” OR “physical activity” OR “physically active” OR pedestrian* OR exercis* OR sedentary) AND (neighborhood OR “physical environment” OR “urban environment*” OR “built environment”) AND (“agent-based model” OR “individual-based model” OR “system dynamics” OR “compartmental model”). Full details of all search terms used in the search strategy for each database are in the Appendix.

2.3. Study selection

After removing duplicates, the studies were examined independently by two team members first by title and abstract for clearly

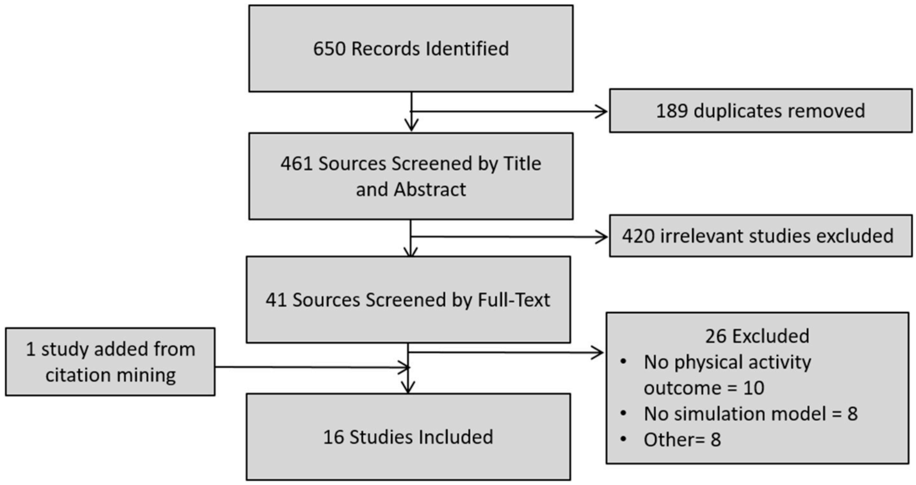

Fig. 1. Study selection process.

non-eligible articles and second by full-text. The two team members discussed and resolved any discrepancies in inclusion/exclusion decisions. To be included in the review, the studies were required to: 1) present a computer simulation model that included built environment or transportation related influences, 2) include physical activity (or physical activity related behavior such as walking or active transport) as a parameter in the model, and 3) include a human population (child or adult). Studies were excluded if they: 1) involved regression-based forecasting models (due to their limited ability to account for interconnected, heterogeneous factors), 2) did not explicitly model or report on a physical activity parameter, 3) involved only models of pedestrian movement for the purposes of understanding issues such as crowding, congestion, and flow, 4) involved only models of traffic-related pedestrian injuries, or 5) were reviews or 'calls to action' to use simulation models. Review articles were, however, mined for additional potential studies for inclusion.

2.4. Charting the data

The research team developed the a data abstraction form with characteristics that would best answer the two main research questions and also included abstraction criteria informed by simulation modeling reporting guidelines (Grimm et al., 2010; Eddy et al., 2012; Rahmandad and Sterman, 2012). After a preliminary review of the articles and testing abstraction of information, the team met and discussed changes needed to the abstraction form. Subsequently, two research team members extracted information from the final articles by entering desired characteristics and elements from the studies into a data abstraction form in an Excel spreadsheet. One research team member led abstraction of each article and the second performed a quality review of the abstraction form. Specific data abstracted included: type of simulation model, research questions/objectives, population and demographics, setting, type of physical activity variable included in the model, active design/built environment strategies evaluated, key findings, stakeholder involvement, and implementation/dissemination implications. We also captured basic elements of the model including: data sources, rules or factors that guided physical activity behavior, descriptions of uncertainty and sensitivity analyses, and a summary of model testing/validation, if any.

2.5. Collating the results

To synthesize results, we first created data tables to summarize study characteristics and conducted qualitative thematic analysis. Specifically, we categorized studies by key themes of the active design and built environment strategies that were evaluated. We further summarized findings to answer our first research question by focusing on the extent of intervention types and heterogeneity of contextual influences that were considered by the simulation studies. Finally, we extracted information related to real-world use of the simulation models for implementation guidance, including the extent to which stakeholders were engaged with the model.

2.6. Consultation

Consultation is an optional stage of the Arksy & O'Malley (Arksey and O'Malley, 2005) scoping review framework with the purpose of obtaining additional sources of information, meaning, and applicability to the scoping study. Our specific purpose was to obtain additional information from study authors about the use of the models by practitioners or policy-makers. We considered this an important component since stakeholder engagement and practical applications are not always reported within the confines of academic research articles. We emailed the corresponding authors of each study and asked for a response to the following questions:

- "To your knowledge, has your model been used by practitioners/ policy-makers to make decisions about policy, programs or interventions?"
- "If yes, do you have any written documentation of how the model has been used that you would be willing to share?"

3. Results

We retrieved and screened a total of 461 non-duplicate citations. Fig. 1 provides a flow chart of the study selection process, which resulted in the inclusion of 16 studies.

3.1. Overview of reviewed studies

Table 1 provides an overview of study characteristics. Of the 16 included studies, 13 used an agent-based simulation model and two used microsimulations. Microsimulation models simulate individual units (e.g., people) by providing each unit a set of operating rules, often based on deterministic or stochastic probabilities that direct how the individual behaves based on different conditions (e.g., changes in the environment). Agent based models are a form of microsimulation, but generally involve more detail about how the individual 'agents' (e.g., people) interact with each other and their environment over time (Epstein, 2007). One other study (Brondeel et al., 2017) used random forest prediction models, a form of machine learning that uses random subsets of data features to build a predictive model of an outcome

Table 1
Overview of study characteristics.

Citation	Type of Simulation Model	Physical Activity Research Question(s)/objective (s)	Population and Example Characteristics	Location/Setting	Physical Activity Measure
Proof-of-Concept Applications					
Yang et al. (2011)	ABM	How do spatial patterns of built and social environments contribute to social inequalities in walking in the context of residential segregation by SES?	108,000 working adults assigned various demographics: gender, age, SES, workplace	Hypothetical city - 64 km^2 city, comparable in size to Ann Arbor, MI with similar characteristics	Walking trips per day per person; Mean and median distance per trip
Jin and White (2012)	ABM	How do different neighborhood designs impact trip and traffic patterns?	Unclear size. SES characteristics of households and household members.	Ottawa, Ontario, Canada	Walking for transportation (vs. car or transit trip)
Yang et al. (2012)	ABM[a]	What is the impact of improving people's attitudes towards walking, improving safety, and their interaction on walking? And is their effect modified by mixed land use?	108,000 adults (see Yang Y. et al., 2011)	Hypothetical city (see Yang. et al., 2011)	Walking trips per day
Yang and Diez-Roux (2013)	ABM	What is the utility of agent-based models in exploring how various policies may influence children's active travel to school?	3000 households, each household has one child	Hypothetical city - 8 km^2	Percent of children walking to school
Yang et al. (2014)	ABM[a]	What is the impact of a walking school bus on children's active travel to school?	Population density varied: 1,000–16,000 households, which translated to 250-4,000 students per school	Hypothetical city	Percent using active transportation
Yang et al. (2015)	ABM[a]	How does travel cost alter walking behaviors under different levels of residential segregation? What are the synergistic effects of policies aimed at changing attitudes towards walking and driving with travel cost policies?	100,000 adults grouped into 50,000 households (two adults in each household), randomly assigned income quintile and social networks	64 km^2 city, in a grid of 800[a]800 m grid space, each 10 m^2 grid is occupied by a location or is empty	Percentage of trips made by walking
Aziza et al. (2016)	ABM	How does variation in opportunities for physical activity in the physical environment influence physical activity levels and, subsequently, BMI?	1000 children, all began at age 6, equal boys and girls	Unclear other than a 2 dimensional grid was used	Minutes per day of MVPA
Ligmann-Zielinska et al. (2016)	ABM	To what extent does accessibility to physical activity facilities influence BMI change? Do different configurations of the built environment affect walkability? How does neighborhood safety effect exercise and, as a consequence, BMI dynamics?	753 (see Table 3.1 – number of agents), assigned sex, age, race and income	3 districts within the city of San Diego, CA	Workout duration (hours) and intensity (calories burned per minute), which was used to calculate total calories burned
Orr et al. (2016)	ABM	To what extent does improving physical activity infrastructure reduce the difference in BMI between blacks and whites in the US?	5120 (64 neighborhoods x 25 households x .80 occupied households = 1280 households; 1280 households x 4 agents per household) assigned economic and racial distributions of black and Non-Hispanic whites in the 100 largest metropolitan statistical areas in the US	64 neighborhoods based on US metro statistical areas	Measure of MET-hours
Real-World Applications					
de Nazelle et al. (2009)	Microsimulation	What is the potential risk of increased air pollution exposure that may result from a hypothetical transformation of the urban landscape towards a more walkable community?	85 individuals - activity patterns and location of activities was generated from a database; Weight, resting metabolic rate are assigned based on age and gender	Orange County, NC	Time in active travel, METs, and body mass were combined to calculate the total energy expenditure from active travel for each agent.
MacDonald Gibson et al. (2015)	Microsimulation	What are the potential effects of a new small-area plan on the incidence of premature mortality and chronic disease over a 25-year period?	Not clearly described; assume representative of setting (Raleigh, NC)	A neighborhood in Raleigh, NC - Blue Ridge Road Corridor	Transportation walking time as minutes per day
Lemoine et al. (2016)	ABM	What are the potential effects of transportation infrastructure changes (specifically a bus rapid transit system) on individual walking behaviors in Bogota, Colombia?	188,300 adults, assigned a home and workplace. Home location determines SES, which determines income/day for transportation and probability of having a car.	Bogota, Colombia	Number of minutes walked for transportation per day
Zellner et al. (2016)	ABM	How will transportation improvements help overcome the 'last-mile problem' particularly as they interact with policy shifts including changing in parking and fuel costs?	106,711 households in 4 neighborhoods, assigned a mix of low/high income; some characteristics based on neighborhood (e.g., probability of auto ownership); others were assigned regardless of neighborhood (e.g.,	Four neighborhoods in Chicago, IL	Active modes of commuting - biking to destination; walking to train; biking to train

(*continued on next page*)

Table 1 (*continued*)

Citation	Type of Simulation Model	Physical Activity Research Question(s)/objective (s)	Population and Example Characteristics	Location/Setting	Physical Activity Measure
			probability of bike ownership, distribution of parking cost)		
Brondeel et al. (2017)	Random Forest Prediction Model	What is the impact of transport mode shifts on transport-related physical activity? What impact would transport mode shift policies have on the magnitude of inequalities in transport-related physical activity by educational levels?	21,332 (See Table 2 notes), participants were aged 35–83 years old, assigned characteristics of gender, education, income, and work situation.	French capital region	Transportation related MVPA
Powell-Wiley et al. (2017)	ABM	What is the impact of crime on physical activity location accessibility, leisure-time physical activity, and obesity among African American women?	Unclear, women in Wards 5, 7, and 9 of DC. Women were ages 18–65, assigned various characteristics, including age, household location and income	Washington, DC	Probability of exercise, with probabilities assigned to the exercise intensity at different locations; METs calculated
Aziz et al. (2018)	ABM	How can an agent-based model (ABM) assist decision makers examine the impact of changes in walk-bike infrastructures at a high spatial resolution (e.g., block group level)?	Unclear. Ages 16 and older, and assigned attributes such as age, income, education, and family structure	New York City, NY	Number/proportion of agents walking or biking to school or work

Notes: ABM = Agent Based Model; MVPA = Moderate to Vigorous Activity; BMI = Body Mass Index; SES = Socioeconomic Status.

[a] Yang, Y., et al. (2012) was an adaptation of Yang, Y., et al. (2011). Yang, Y., et al. (2014) was an adaptation of Yang, Y. and Diez-Roux, A. (2013). Yang, Y., et al. (2015) was an extensive revision of Yang, Y., et al. (2011) and Yang, Y., et al. (2012).

(Strobl et al., 2009).

Of the 16 studies included, seven were real-world applications (models used mostly real-world data and answered questions that were applied to a specific population) (Brondeel et al., 2017; de Nazelle et al., 2009; MacDonald Gibson et al., 2015; Lemoine et al., 2016; Zellner et al., 2016; Powell-Wiley et al., 2017; Aziz et al., 2018) and nine were proof-of-concept (models used mostly hypothetical populations and parameters to answer conceptual questions) (Yang et al., 2011, 2012, 2014, 2015; Jin and White, 2012; Yang and Diez-Roux, 2013; Aziza et al., 2016; Ligmann-Zielinska et al., 2016; Orr et al., 2016). The geographic environment for six of nine proof-of-concept studies were stated as hypothetical cities (Yang et al., 2011, 2012, 2014, 2015; Yang and Diez-Roux, 2013; Aziza et al., 2016); the remaining three specifically referenced that their environment and population was representative of US cities generally (Orr et al., 2016) or of a specific city (Ottawa, ON, Canada (Jin and White, 2012) and San Diego, CA (Ligmann-Zielinska et al., 2016)). Of the seven real-world applications, five were urban areas in the US (de Nazelle et al., 2009; MacDonald Gibson et al., 2015; Zellner et al., 2016; Powell-Wiley et al., 2017; Aziz et al., 2018) and one each were urban areas in France (Brondeel et al., 2017) and Colombia (Lemoine et al., 2016).

Among all studies, physical activity was most often (10 studies) incorporated into the models as a variable related to modes of transportation and was often based on a relatively coarse measures of physical activity (e.g., categorical function of transportation mode, number of walking trips per day) (MacDonald Gibson et al., 2015; Lemoine et al., 2016; Zellner et al., 2016; Aziz et al., 2018; Yang et al., 2011; Jin and White, 2012; Yang et al., 2012; Yang and Diez-Roux, 2013; Yang et al., 2014; Yang et al., 2015). The remaining six studies included physical activity as a function of exercise and used more fine-grained measures of physical activity (e.g., minutes of moderate to vigorous activity, calories burned, metabolic equivalent hours per week) (Brondeel et al., 2017; de Nazelle et al., 2009; Powell-Wiley et al., 2017; Aziza et al., 2016; Ligmann-Zielinska et al., 2016; Orr et al., 2016).

There was wide variation in model description and documentation. Six studies included detailed supplementary material (Brondeel et al., 2017; MacDonald Gibson et al., 2015; Lemoine et al., 2016; Powell-Wiley et al., 2017; Yang et al., 2011; Orr et al., 2016) and all others relied on citations to other sources or limited their description to the main body of text. Notably, no authors systematically described their model and details of their study as recommended by many best practice frameworks (Müller et al., 2013; Halpern et al., 1998; Caro et al., 2012). Most articles reported some form of validation or calibration analyses. However, details were not always provided about the specific parameters of the validation or calibration. Uncertainty (evaluation of how uncertainty in model parameters influences changes in key outcomes of interest) and sensitivity (evaluation of the magnitude of change in model outcomes when parameters are varied across a range of potential values) analyses were also present throughout most of the studies. However, deterministic or probabilistic uncertainty analyses were rarely used to quantify the uncertainty of calibrated parameters.

3.2. *Types of interventions evaluated*

Studies examined a wide variety of built environment and transportation-related features (Table 2). Safety was the most common feature evaluated and was simulated by varying factors such as the crime rate, perceptions of crime, or perceptions of traffic safety (Powell-Wiley et al., 2017; Yang et al., 2011, 2012, 2014, 2015; Yang and Diez-Roux, 2013; Ligmann-Zielinska et al., 2016). The next two most frequently evaluated features were related to public and school transit design (Brondeel et al., 2017; Lemoine et al., 2016; Zellner et al., 2016; Yang et al., 2014), (in which models examined factors such as adding more public transit stations or routes), and land use design (Yang et al., 2011, 2012, 2015; Yang and Diez-Roux, 2013) (in which models examined different densities and distributions of residential and non-residential

Table 2
Types of built environment-related features and interventions evaluated.

Environmental Features	Description	Examples of Model Implementation	Aligned Community Preventive Services Task Force (CPSTF) Recommendation
Safety (Powell-Wiley et al., 2017; Yang et al., 2011, 2012, 2014, 2015; Yang and Diez-Roux, 2013; Ligmann-Zielinska et al., 2016)	Changes to the level of safety or perceived safety related to physical activity (e.g., neighborhood crime, perceived pedestrian safety)	- Varying the crime rate - Varying individual's perception of crime - Varying individual's perception of traffic safety	- not reviewed by CPSTF
Public and school transit design (Brondeel et al., 2017; Lemoine et al., 2016; Zellner et al., 2016; Yang et al., 2014)	Changes to logistical operations of public transportation (e.g., bus, train, tram) such as transit stops, number of lines, speed	- Adding bus lanes - Adding transit stops - Use of automated shuttles - Changes to school bus routes	- Public transit infrastructure and access
Land use design/zoning (Yang et al., 2011, 2012, 2015; Yang and Diez-Roux, 2013)	Changes to the mixture or density of residential and non-residential (e.g., workplaces, grocery stores, small businesses) areas in a community	- Increase mixed use areas (i.e., include both residential and non-residential locations) - Changes to amount of residential segregation by income	- Mixed land use - Increasing residential density
Comprehensive neighborhood design (de Nazelle et al., 2009; MacDonald Gibson et al., 2015; Orr et al., 2016)	Changes to neighborhoods that involve multiple factors of potential to influence physical activity such as land use, street connectivity/ intersections, sidewalks, public transportation access points	- Full neighborhood re-design to change street connectivity, sidewalks, mixed use areas - Increase of a composite index of the neighborhood environment that includes land use, public transportation access, etc.	- Combination of all recommendations
Road/Route design (Jin and White, 2012; Ligmann-Zielinska et al., 2016)	Changes to the lay-out of different types of roads or routes that influence appeal of walking or distance to common destinations (e.g., schools)	- Comparison of a 'neo-traditional' versus a 'fused grid' road design - Numbers of walkable roads	- Street connectivity - Pedestrian infrastructure - Bicycle infrastructure
Walking/biking streetscape improvements (Zellner et al., 2016; Aziz et al., 2018; Jin and White, 2012; Ligmann-Zielinska et al., 2016)	Changes to the streetscape that increase safety and appeal of biking or walking	- Adding bike lanes - Widening sidewalks - Improvements to street landscaping	- Pedestrian infrastructure - Bicycle infrastructure
Transportation-related monetary incentives/disincentives (Zellner et al., 2016; Yang et al., 2015)	Creating disincentives for driving or incentives for walking or using public transportation	- Increased cost of fuel - Increased parking fees - Reductions in public transit fare	- not reviewed by CPSTF
Access to physical activity spaces (Aziza et al., 2016; Ligmann-Zielinska et al., 2016)	Changes that improve access to spaces that are favorable or create opportunities for physical activity	- Provide gym access - Vary an index that measures how favorable the environment is for physical activity	- Parks and recreational facility access

locations). Four studies evaluated walking/biking streetscape improvements (Zellner et al., 2016; Aziz et al., 2018; Jin and White, 2012; Ligmann-Zielinska et al., 2016), and three studies evaluated comprehensive neighborhood design (de Nazelle et al., 2009; MacDonald Gibson et al., 2015; Orr et al., 2016). Studies that evaluated comprehensive neighborhood design modeled simultaneous changes to multiple inter-connected factors that had potential to improve physical activity such as street connectivity. Studies that evaluated walking/biking streetscape improvements simulated changes such as adding bike lanes or widening sidewalks to improve walkability/bike-ability. Relatedly, two studies also evaluated road/route designs by examining changes to the types of and layout of roads or routes to frequent destinations that could make walking or biking more appealing (Jin and White, 2012; Ligmann-Zielinska et al., 2016). Finally, two studies each examined transportation-related monetary incentives or disincentives (Zellner et al., 2016; Yang et al., 2015) and access to physical activity spaces (Aziza et al., 2016; Ligmann-Zielinska et al., 2016). The transportation related monetary (dis)incentives involved variations in factors such as parking, gas, and public transit fares. Access to physical activity spaces involved changes that made exercise more favorable such as decreasing distance to a gym.

3.3. Evaluation of heterogeneity

Most studies evaluated how the effect of either the built environment changes on physical activity would vary based on heterogeneity of the local context. For example, Zellner et al. (2016) modeled their agents and environments after four distinct neighborhoods of the Chicago Metropolitan Region. They found that the impact of parking costs, streetscape improvements, and increased shuttles services had a different effect for each of the four neighborhoods based on factors such as levels of public transit service at baseline. Yang et al. (2012) varied the distribution of non-residential areas and safety in a hypothetical city and found that while safety improvements may be beneficial to improve walking behaviors in low socioeconomic status neighborhoods, the effectiveness was greatest when those neighborhoods also had a high density of non-residential space.

3.4. Translational characteristics of the studies

Studies that were proof-of-concept (n = 9) often indicated the potential utility of their models to inform policy and decision-making, but the need for empirical data in order to make them applicable to decision-makers. Across all 16 articles, stakeholder engagement was briefly described in only one article (MacDonald Gibson et al., 2015). The outcomes under various intervention scenarios were often displayed in tabular or graphical format, with wide heterogeneity in readability and ease of interpretation. Only one study attempted to examine cost outcomes; specifically, MacDonald Gibson et al. (MacDonald Gibson et al., 2015) evaluated the potential impact of implementing a small-area plan designed to make a community more pedestrian-friendly. Although they did not estimate the entire cost of implementing the small-area plan, they calculated the cost of installing sidewalks in the community and estimated potential economic benefits that could result from averting adverse health outcomes.

3.5. Model use by practitioners or policy-makers

We received a response for 14 of the 16 studies (10 of 12 corresponding authors, 83%) to our inquiry whether the model had been used by or with practitioners or policy-makers. Most (11 of the 14 articles; 7 of the 10 authors) indicated that the model had not been used by practitioners or policy-makers to their knowledge. Of the remaining three, one responded that the model had been commissioned by a mortgage and housing corporation, but the author was uncertain if and how the model had been used (Jin and White, 2012). A second indicated that the city they worked with used the findings to support their investment decisions in pedestrian and bicycle infrastructure (MacDonald Gibson et al., 2015). The final author responded positively that the model had been commissioned and used by the Federal Highway Administration (Zellner et al., 2016).

4. Discussion

Our scoping review of 16 studies found a substantial growth of simulation studies examining the effects of built environment-related influences on physical activity, with the first appearing in 2009 and half published since 2016. The studies we reviewed highlighted the utility of simulation (especially agent-based modeling) to incorporate interconnections and heterogeneity into the analyses. However, the extent of research in this area is still in early stages and gaps remain. About half of the studies were proof-of-concept, and stakeholder engagement and use of the published models to inform real-world decisions appeared limited. More studies examined safety and features associated with walkability and active transportation (land use and street design, public transportation design) in urban environments, which make decisions related to these areas ripe for real-world application.

Researchers have recommended that more simulation modeling be used to help analyze complex, costly real-world public health decisions and improve the implementation of evidence-based practices (Burke et al., 2015; Tracy et al., 2018; Tracy, 2017). Thus, the growth in studies we found in our review is positive, especially because built environment changes are often major endeavors that are costly to plan and implement. However, it is a concern that stakeholder engagement, efforts to document models to aid dissemination, and use of models to inform real-world policy and practice appeared limited. This is likely reflective of the fact that simulation modeling of built environment influences on physical activity is a nascent area. Also the audience and purpose for simulation studies published in peer-reviewed literature is likely more conceptual and methodological than translational. Nonetheless, simulation modeling has substantial potential to help policymakers and practitioners make decisions about evidence-based interventions and overcome widely documented research-to-practice gaps, and simulation researchers should take heed of calls for more pragmatic research to hasten translation (Green et al., 2009; Institute of Medicine Committee on Quality of Health Care in America, 2001).

In our review, we found that some areas of the built environment have received more attention than others. The studies in our review mostly evaluated interventions and features that were related to neighborhood safety (crime or traffic), active transportation, land use design, and walking and biking infrastructure. These types of built environment interventions aligned well with those recommended by the Community Preventive Services Task Force (Table 2) (Community Preventative Services Task Force, 2016). However, only two studies assessed features more specifically related to access to recreational facilities, also recommended by the Task Force.

We uncovered an important gap related to the populations and settings studied. All of the studies reviewed involved urban populations and settings, which is understandable given the nature of the urban environment and form. However, researchers have made calls for a greater focus on research to understand built environment influences in rural areas (Umstattd Meyer et al., 2016) given known disparities in urban-rural physical activity patterns (Fan et al., 2014, 2017; Martin et al., 2005). Moreover, only a few studies evaluated effects based on income and racial disparities. Simulation models provide an opportunity to assess influences given heterogeneity in factors such as urbanicity, income, or race, which could help researchers to examine how changing the built environment may reduce or exacerbate disparities.

5. Limitations

This review has several limitations. A description of stakeholder engagement is not necessarily the focus of the peer-reviewed research articles. Thus, there has possibly been more stakeholder engagement than we uncovered in our survey of authors. As in all reviews, we had to balance the search terms we used to return a wide but realistic number of articles. For example, we limited our search terms to synonyms of individual and compartmental simulation models and omitted other non-specific terms (e.g., in silico, nonlinear dynamics, complex adaptive systems) because their inclusion yielded large (85,000+) and unfocused numbers of articles. It is possible that in narrowing our search, some articles were inadvertently omitted. Finally, we did not search the grey literature, which would have potential to uncover additional projects that used simulation but were not published in peer-reviewed journals.

6. Conclusions and recommendations

Our scoping review highlighted content and methodological concerns upon which to base future research recommendations. In terms of content, we found gaps in both the types of interventions and populations examined that deserve more attention in simulation studies. Methodologically we found that more research is needed to overcome gaps in translating simulation research to practice and there is a need for more systematic model documentation.

More research is needed that examines features related to recreational physical activity and gives greater consideration to heterogeneity of effects on populations with known disparities (e.g., rural/urban, income, or race). Reviews of observational and experimental studies about built environment influences on physical activity also suggest that comparatively fewer studies have focused on recreation-related features compared to transportation or safety-related features (Smith et al., 2017; Masoumi, 2017). Although fewer, the studies that have focused on recreation-related features have provided evidence that the influence of recreational environments (fitness centers, parks, green spaces) is substantial, especially among children and youth (Clark et al., 2014; Quigg et al., 2012; Kaczynski and Henderson, 2008). More simulation studies could use existing observational and experimental studies to inform model parameters. Existing data for models related to populations with known disparities may be less readily available. Thus, simulation studies in these areas may need more resources to collate more fragmented sources of data or to conduct primary data collection studies to inform model parameters.

With regard to translational methodology, we found that there is a greater need for research to engage stakeholders with simulation model development and interpretation. Stakeholders include individuals from public health and environmental planning practitioners, city and county governing bodies, or state departments of health. Stakeholder engagement early in the model building process can help ensure that the model is realistic and meaningful, feasible interventions are tested, and results are interpreted effectively (Hammond, 2015). For example, only one study (MacDonald Gibson et al., 2015) included cost in the model; however, implementation and maintenance costs are likely critical decision-making criteria. Furthermore, no studies involved discussions regarding feasibility or acceptability of potential built environment related changes. There is a clear need for research to consider what the barriers have been to stakeholder engagement in simulation modeling, and evaluate what types of engagement practices most effectively and efficiently inform decisions. For example, group model building practices that involve stakeholders in a series of workshops from initial problem identification, to model development, to using a simulation model to guide decision-making is recommended (Frerichs et al., 2016; Andersen et al., 2007; Rouwette et al., 2002), but it is resource and time-intensive and may not be acceptable to some decision-makers. Other, less intensive, strategies such as "gamification" of models (i.e., the application of gaming principles and design to model use in a non-game context) (Huotari and Hamari, 2012) and use of online platforms that allow for more interactive involvement of stakeholders should be considered and evaluated.

In order to advance the science of translation in simulation studies, challenges about how to balance 'simple but realistic' and 'specific but generalizable' simulation models to improve dissemination must be considered (Klosterman, 2012). Creating highly realistic models that include the infinite numbers and interconnections of built environment and health-related variables can lead to highly complex, large, and expensive models that may be difficult to use across different settings, but can be uniquely capable of providing detailed and relatively confident predictions about policies and interventions. In contrast, creating simple models that focus on some aspects of reality but omit more details can lead to greater risk that important processes are omitted, but may be more flexible to use across different settings to explore stakeholder assumptions and possible futures related to policies and interventions. Researchers should strike this balance based on their own purpose and needs. In the future, researchers with more complex models need to carefully consider how to make model outcomes and complex 'under the hood' model elements transparent, while also being understandable to stakeholders without modeling experience. It is important to ensure that outcomes are presented in an intuitive manner that decision-makers can easily interpret and draw conclusions from. Researchers with more simplistic models that less fully reflect reality need to carefully consider the role they should play in decision-making. For example, simple models could promote open debate about model assumptions and inform democratic decision-making.

Finally, we also found that descriptions of the model varied widely and made comparisons and assessment of research quality challenging. For example, documentation of model assumptions, the theories that underpin agent decision-making, the population of interest, equations used, or agent flow throughout the model varied greatly between included studies. Protocols for reporting modeling studies have been emerging and becoming more established in recent years and may have been less available for the researchers of the reviewed studies. Future studies should follow such reporting protocols (Müller et al., 2013; Halpern et al., 1998; Caro et al., 2012) to help ensure that important aspects of the model are not omitted and improve comparability between various models built by different research groups with different data sources.

In conclusion, we found that simulation of built environment-related influences on physical activity is an emerging area of importance to public health and environment planning. We found gaps in specific content areas that should guide future research. Importantly, more work to understand how to engage stakeholders and build policy-relevant models is needed to improve the potential for this type of research to inform real-world decisions.

Appendix A . Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.healthplace.2019.04.001.

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