Anuário do Instituto de Geociências
Universidade Federal do Rio de Janeiro
https://revistas.ufrj.br/index.php/aigeo/

ISSN 0101-9759
e-ISSN 1982-3908

Create of a Conceptual Framework for the Use of an Agent-Based Modeling in Urban Studies with an Emphasis on the Walkable City

Desenho de um Quadro Conceitual para a Utilização de Modelos Baseados em Fatores nos Estudos Urbanos com Ênfase na Cidade Caminhável

Masoud Zamanipoor, Mohammad Rahim Rahnama & Mohammad Ajza Shokouhi

Ferdowsi University of Mashhad, Department of Geography, Mashhad, Iran
E-mails: ma.zamanipoor@mail.um.ac.ir; rahnama@um.ac.ir; shokouhim@um.ac.ir
Corresponding author: Masoud Zamanipoor; ma.zamanipoor@mail.um.ac.ir

Abstract

Agent-based modeling by a bottom-up approach has shown that it has enough capacity to provide a natural definition for urban complicated system. During the last two decades, numerous studies have been dedicated to investigate the influence of urban policies on people's tendency to walk using an agent-based approach. Therefore, it is considered to be the right time to meta-synthesize experiences and aggregating data into a unit in order to create a comprehensive framework for these studies. With this in mind, in this study, we aim to meta-synthesize these experiences to create a comprehensive framework in order to use agent-based modeling to investigate the influence of urban design and planning policies on people's tendency to walk. This study revealed that "basic model", "disruptor" and "operation" made up the crucial elements of framework.

Keywords: Tendency to walk; Meta-synthesis; Urban design

Resumo

A modelagem baseada em agentes através de uma abordagem ascendente mostrou que tem capacidade suficiente para fornecer uma definição natural para o sistema urbano complexo. Durante as últimas duas décadas, muitos estudos têm sido dedicados a investigar a influência das políticas urbanas na tendência das pessoas para caminharem e utilizando uma abordagem baseada em agentes. Portanto, considera-se o momento certo para meta-sintetizar experiências e agregar dados em uma unidade, a fim de criar uma estrutura abrangente para esses estudos. Tendo isto em conta, o nosso objetivo é meta-sintetizar essas experiências para criar uma estrutura abrangente a fim de usar a modelagem baseada em agentes que investiga a influência do desenho urbano e das políticas de planejamento na tendência das pessoas a caminhar. Este estudo revelou que "modelo básico", "disruptor" e "operação" constituíam os elementos cruciais do enquadramento.

Palavras-chave: Tendência das pessoas a caminhar; Meta-síntese; Design urbano

Received: 07 August 2022; Accepted: 07 November 2022

1 Introduction

History of computer simulation modeling in urban studies can be traced back to the 1960s (Lowry 1965) after the introduction of scientific concept of urban system following botanic technical terms (Duncan et al. 2013). Simulation models have tried to provide a descriptive and predictive-based recognition using a virtual-based model. These models became more prominent in investigations due to the progress of computers' capabilities. As Casti (1997) notes: "for the first time in history, we have the experimental tools with which to begin the creation of a bona fide theory of complex and adaptive systems". Simpson (2001) provides a comprehensive literature of the functions of simulation models in urban studies. His study showed that through the combination of virtual reality, spatial modeling and GIS in urban simulations, we are permitted to ask questions which were impossible before and now, we can even respond them. Take, for example, when a study aims to locate the supermarkets all over the city using an agent-based modeling, through the alternation of supermarkets' location policy change, the change of people's traveling behavior as well as other factors like traffic and city pollution can be analyzed as a virtual reality (Abel & Faust 2020).

In spite of the long history of an agent-based modeling (ABM), it was in the 1990s that this paradigm became mature in terms of both computational and conceptual in order to be implemented in urban studies as a feasible simulation tool. Comparing to the common modeling methods, this method has some advantages which make it suitable in urban studies. Bonabeau (2002) has expressed the most important advantages of it in three statements: (a) using an up-down approach to show the phenomena which have emergent potential, (b) providing a natural description for a system, for example, a simulation of people's movement in a neighborhood seems more natural than the equations which emphasize on dynamic of people's density in a neighborhood, (c) is more flexible toward any changes such as environmental changes or agents' behavioral principles.

The ABM is being implemented in various urban studies, such as city growth (Li et al. 2020; Alghais & Pullar 2018; Arsanjani, Helbich & de Noronha Vaz 2013), urban transportation (Barthelmes et al. 2022; Fazio & Peña 2021; Ben-Dor, Ben-Elia & Benenson 2018), urban health (Almagor et al. 2021; Mayne et al. 2017, Yang et al. 2011), etc. This study does not aim to provide a comprehensive investigation and a conceptual framework for the use of ABM in such a comprehensive literature, but instead focuses on the design of a conceptual framework for the use of an ABM in one of the most significant issues of urban design, i.e., walkable city.

Walkable cities can be defined by how a built environment is useful for pedestrians (Habibian & Hosseinzadeh 2018; Taleai & Amiri 2017). Therefore, the tendency to walk is usually being evaluated by the change in the built environment (e.g., Ahmadipour, Mamdoohi & Wulf-Holger 2021; Bozovic et al. 2021). Using various frameworks and approaches, city experts consider ABM to evaluate the influences of environmental policy changes on the people's tendency to walk.

Badland et al. (2013) considered these four items constant: maximum time of walking, walking speed, max. distance of walking and waiting time at crossroads. They, then, changed the environment and created new plans which signal the change of pedestrians' behavior (Badland et al. 2013). Lemoine et al. (2016) implemented an ABM to study the influence of transportation's infrastructure on walking in the city of Bogota. They provided each agent with living place, workplace and socio-economic status (SES) with which, some income was dedicated for the transportation of each. Based on the resources and the needed traveling time, people were decided to choose a mean from among the available means of transportation (e.g., taxi, car, bus, BRT and walking) to reach their destination.

Aziz et al. (2018) created an ABM to support New York's investigation decisions with which they could evaluate the influence of changes in walking and biking infrastructures on citizens' traveling behavior. In another study, Abel and Faust (2020) created a comparative framework to simulate the food deserts of Austin's neighborhoods and evaluated which disruptor of built environment, e.g., development of bus lines, improvement of pedestrians'' safety infrastructures and new supermarkets, are the most influential in food availability. To create integral transportation infrastructures and public space systems considering the pedestrians' behaviors, Yang et al. (2020) developed a consistent technique which included an agent-based simulation model, serious games and a cooperative design that could provide citizens with new opportunities to cooperate in city planning process. Filomena and Verstegen (2021) also used ABM to study the role of city landmarks in finding routes. They compared together route choice models with and without the landmarks using four scenarios.

The study of Scopus and Web of Science (WOS) databases demonstrates that some studies have been conducted in the last two decades in order to investigate the influence of urban policies on tendency to walk using an agent-based approach. This process has become more serious in the last decade some of which were reviewed in the last paragraph. This is why after two decades of studies in this field, new opportunities have been provided to gain comprehensive insights into the current experiences as well as new theoretical findings to develop this field of study. Therefore, through the collection of various experiences in this field, this study aims to form a comprehensive framework to use ABM in order to investigate the influences of urban policies on people's tendency to walk. In this end, the questions of this study include:

> -What are the major categories of a conceptual framework to study the influence of urban policies on tendency to walk using agent-based modeling?
>
> -How can these categories form an agent-based simulation framework in order to investigate the influence of urban policies on tendency to walk?

2 Methodology

The methodology of this study is based on a seven-step guideline, i.e., framing a meta-synthesis, locating relevant papers, deciding what to include, appraisal of studies, analysis technique, reciprocal translation and synthesis of translation (FLDAARS), which was recommended by Walsh and Downe (2005) to study the meta-synthesis. These steps can be divided into three main parts: input delimitation, findings and output adjustment (Figure 1).

During the first four steps, the input data pass through various filters in order to be extracted and analyzed. Developed questions can form the frame of this study. Scopus and WOS were used to search for articles. To search in these bases, keywords and standards were defined based on Table 1.

To define keywords, study questions were separated into sections first. These sections included "agent-based approach", "built environment" and "tendency to walk". The keyword to search for "agent-based approach" was "agent-based". The keywords for "built environment" were built environment, residential density, population density, welfare infrastructures, number of jobs, applicability, retailing jobs, availability of facilities, availability of favorite spots, availability of public transportation, availability of parking lots, closeness to the downtown, availability of CBD, number of crossroads, block's length, relationship between knot and tie, cul-de-sac, streets' density, footpath continuity, nearness of the footpath, space arrangement, pavement, gradient, greenness, density of trees, tree canopy cover, shadow wideness, sunray, traffic safety, police stations, visual surveillance systems, streets' lightening, area, signs, human scale, buildings' density, views and neighborhood. The keywords for "tendency to walk" were pedestrians, walking capability, walking and physical activities. Searching strategies applied on WOS and Scopus databases found 95 and 75 articles, respectively.

In the third step (i.e., decide to include), a structure like the one in Figure 2 is being implemented in order to decide whether to accept or reject the articles (Fonseca et al. 2021; Rachele et al. 2019; Yi et al. 2019). Titles, abstracts and keywords were investigated manually to

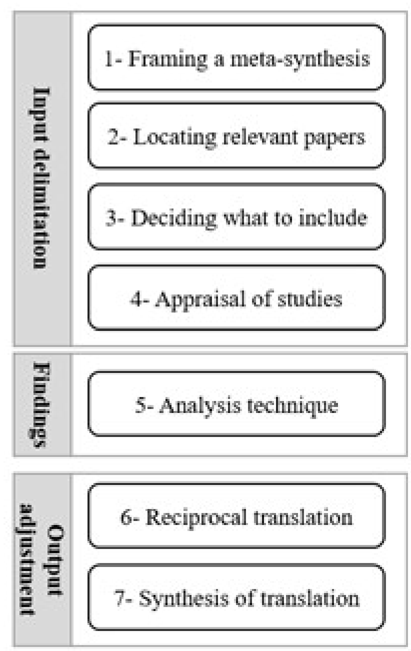

Figure 1 Meta-synthesis Process (Walsh & Downe 2005).

Table 1 Definition of search standards in the first step.

Standard	Standard domain
Article's language	English
Date of publication	Articles published from 1970 to 2021.5.24
Subject of the article	Investigation of the influence of urban policies on tendency to walk using ABM
Type of study	Articles published in journals and international conferences
Research information's situation	Articles with transparent research findings and process
Database	Scopus and Web of Science webbases

determine which articles are fully appropriate for this issue. Repetitive publications, documents without complete texts and documents in which the title of this research was a minor issue, were eliminated. Finally, 29 articles, among 170 studied articles, were determined appropriate for this research. The research findings revealed that the first appropriate article was Turner and Penn (2002). In 4th step (appraisal of studies), the remained articles were controlled with CASP checklist questions and then all the remained articles were determined to be valuable to study.

The analysis technique step is also called "extraction of results or data" (Labrie et al. 2021) which was implemented in this research. An extraction form to organize information during the articles' review was prepared. The extracted data included documentary data like article's title, authors, etc. as well as technical data like features of the built environment, ABM's sections, etc. Due to their conceptual similarity, technical data were divided into some categories and subcategories which are provided in "Findings" section.

The last part of meta-synthesis is output adjustment. In this part, first, the translation of one study's findings to another study was conducted using metaphors and concepts. In the final step (synthesis of translation), the transmitting data were either corrected or interpreted to clarify concepts better and explore the theory in order to conclude on the main concepts and create an ABM comprehensive conceptual framework to investigate the influence of urban policies on tendency to walk.

2.1 Output Validation

Validation of meta-synthesis can be evaluated by either professionals' opinion (Sandelowski & Barroso 2006) or using it in a case study (Thorne 2009). Professionals' opinion was applied to validate the research. In this end, 12 professionals were called for cooperation among which 8 professionals accepted our call to cooperate. These professionals were independent from the research team. To validate the created framework, the professional group was provided with the relevant documents of all the research sections. The feedback that was provided by the group step-by-step was collected and studied. The feedback was then consulted with a two-member panel of academic experts as referees. Finally, the results that derive from referees were applied in various steps of the framework's architecture. The questions which generally determined the surveying atmosphere included the following:

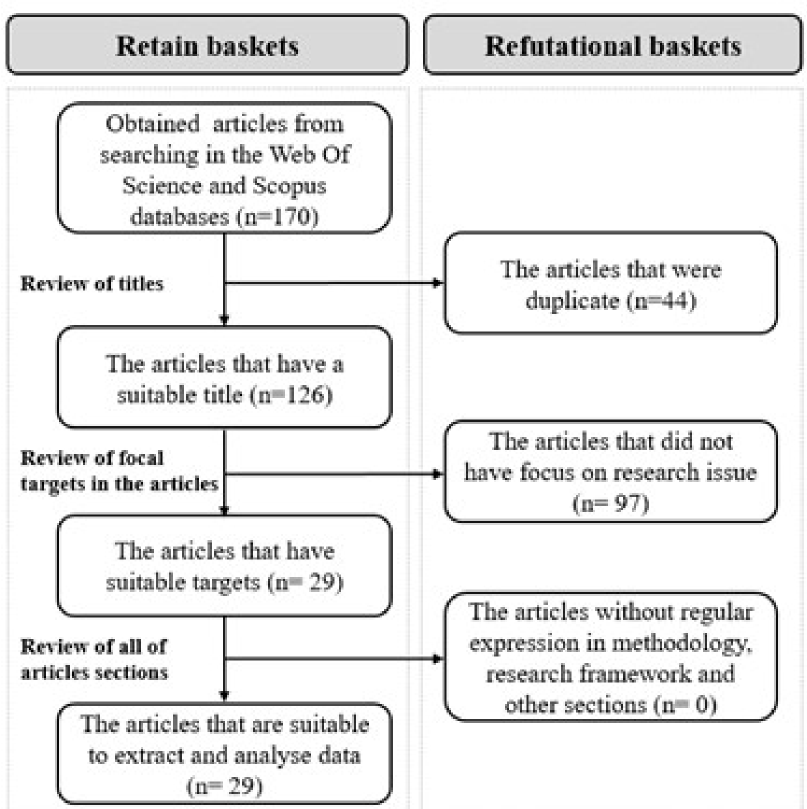

Figure 2 Literature review structure.

-Can the research questions truly demonstrate the research framework?

-Is the process of article finding well-developed?

-Is the process of selecting appropriate articles well-suited with the research title?

-Is the technique of mining concepts and their categorization credible?

-Is the process of findings' translation and their synthesis for the purpose of creation the recommended framework appropriate?

3 Findings

In this section, the extracted articles were fully studied initially. Then, those concepts which could be used in this research were selected. The extracted concepts formed the initial findings of this research. Then, according to the common concepts that could be deduced from them, they were divided into specific categories and subcategories. After forming these initial categories, the opposite concepts were transformed among categories and some categories were synthesized. Finally, these concepts were put into categories and sub categories as depicted in the sections below.

3.1 Structure of Simulation Space

After the review of the ABM's experiences, it was determined that the definition of simulation space's structure into various sub categories (Table 2) is considered the first step in modeling process. Due to the modeling goal, this structure can be defined in various dimensions such as demography, features of built environment, modes of transportation in the region and the study's geography.

3.2 Agents

After the conceptual analysis of the extracted concepts in this section, the agents were categorized into three groups, i.e., human, systematic and criterion-based human (Table 3). In all studies, human agent is applied as pedestrians or residents (e.g., Filomena, Manley & Verstegen 2020; Lemoine et al. 2016). Besides the human agent, public transportation system is considered as an agent in Abel & Faust's (2015) study. Omer and Jiang (2015) also defined agents based on the environmental criteria of space-syntax approach.

3.3 Interactions

After defining agent, its interactions need to be determined in the model (Table 4). Findings revealed that in all researches, either in macro or micro scales, it is essential to define the agent's action independently using concepts such as "function", "parameters and functional variables" and "decision's rules". In addition, mostly in macro scale researches, the interactions between agent, environment and other agents require to be considered.

3.4 Scenario

A specific scenario is defined in many researches in order to evaluate the influence of urban policies on people's tendency to walk. In fact, built scenarios are some substitutes for available built environment in order to study the real influence of the newly designed policies on behavior of the agents. These scenarios are being divided into some specific sub categories (Table 5).

3.5 Model Accuracy

Experiences show that after the model is being created, it is calibrated in order to make the model's output similar to the real world's data using various methods (Table 6). This part is a significant part of ABM for the model's accuracy. Therefore, the sub category of calibration is put in model accuracy category.

3.6 Verification and Validation

A variety of methods are applied to improve and evaluate the model's output verify and validity in ABM. These methods are used in Table 7 under the name of their relevant concepts. The final step for ABM is verification and validation (V&V). Based on the concepts and the semantic interdependency among them, V&V category is divided into four sub categories, e.g., "validation of conceptual model", "operational validity", "data validity" and "computer-based verification".

4 Reciprocal Translation

In this step, the main structure of the recommended model is created based on the extracted information and the categories shown in Tables 2-7. As in Table 2, features such as demographical characteristics and built environment, modes of transportation and the study's geography are

Table 2 Extraction of concepts relevant to the simulation space structure categories.

No.	Concepts	Sources	Sub category	Category
1	Family income and socioeconomic status	(Aziz et al. 2018), (Lemoine et al. 2016), (Yang et al. 2015), (Zhu et al. 2013), (Jin & White 2012), (Yang et al. 2012), (Yang et al. 2011)	Demography	simulation space's structure
2	Age	(Aziz et al. 2018), (Lemoine et al. 2016), (Yang et al. 2015), (Yang et al. 2011)		
3	Gender	(Aziz et al. 2018), (Yang et al. 2011)		
4	Identity	(Aziz et al. 2018)		
5	Education	(Aziz et al. 2018)		
6	Owning a dog	(Yang et al. 2011)		
7	Workplace	(Yang et al. 2011)		
8	Ability to walk	(Yang et al. 2011)		
9	Tendency to walk	(Yang et al. 2011)		
10	Friends	(Yang et al. 2011)		
11	Family dimensión	(Aziz et al. 2018), (Yang et al. 2015), (Yang et al. 2011)		
12	Owning a personal car	(Aziz et al. 2018), (Yang et al. 2015)		
13	Crime rate	(Yin 2013), (Gao 2013)		
14	Population density	(Aziz et al. 2018)	Built environment Transportation modes in the region Study's geography	
15	Building density	(Aziz et al. 2018)		
16	Occupation density	(Aziz et al. 2018)		
17	Land use	(Omer & Kaplan, 2017), (Badland et al. 2013), (Yin 2013), (Gao 2013)		
18	Train station	(Zellner et al. 2016)		
19	Buildings	)Filomena & Verstegen 2021(, (Aschwanden et al. 2011)		
20	Places for leisure time activities which are suitable for physical activities	(Garcia et al. 2018)		
21	Origins and destinations	(Filomena & Verstegen 2021); (Filomena, Manley & Verstegen 2020);(Abel & Faust 2020), (Garcia et al. 2018), (Aziz et al. 2018), (Hu et al. 2017), (Lemoine et al. 2016), (Asriana & Indraprastha 2016), (Zellner et al. 2016), (Omer & Jiang 2015), (Yang et al. 2015), (Badland et al. 2013), (Yin 2013), (Aschwanden et al. 2011)		
22	Urban divisions (zonning, selection of the borderlines between neighborhoods and blocks)	(Filomena, Manley & Verstegen 2020), (Aziz et al. 2018), (Zellner et al. 2016), (Yang et al. 2012)		
23	Street network (knots, connections, streets, pavements, …)	(Filomena & Verstegen 2021); (Filomena, Manley & Verstegen 2020); (Abel & Faust 2020), (Garcia et al. 2018), (Aziz et al. 2018); (Omer & Kaplan 2017), (Zellner et al. 2016), (Badland et al. 2013), (Gao 2013), (Yang et al. 2012), (Jin & White 2012), (Aschwanden et al. 2011)		
24	Transportation network	(Abel & Faust 2020), (Lemoine et al. 2016)		
25	barriers (e.g.natural and severe barriers, walls, …)	(Filomena, Manley & Verstegen 2020), (Hu et al. 2017)		
26	Landmarks	(Filomena & Verstegen 2021)		
27	Stores	(Abel & Faust 2020)		
28	Lawscape	(Yang et al. 2021)		
29	Segment analysis	(Filomena & Verstegen 2021); (Filomena, Manley & Verstegen 2020), (Hanna 2021), (Omer & Kaplan 2017), (Omer & Jiang 2015), (Yin 2013)		

Table 2 Cont.

No.	Concepts	Sources	Sub category	Category
30	Walking	(Yang et al. 2021), (Hanna 2021), (Filomena & Verstegen 2021), (Florindo et al. 2021), (Huang, Kimm & Burry 2021), (Filomena, Manley & Verstegen 2020), (Abel & Faust 2020), (Aziz et al. 2018), (Garcia et al. 2018), (Garcia et al. 2017), (Elbanhawy 2017), (Hu et al. 2017), (Huang, White & Burry 2017), (Omer & Kaplan 2017), (Asriana & Indraprastha 2016), (Lemoine et al. 2016), (Zellner et al. 2016), (Omer & Jiang 2015), (Yang et al. 2015), (Fidler & Hanna 2015), (Badland et al. 2013), (Yin 2013), (Zhu et al. 2013), (Jin & White 2012), (Yang et al. 2012), (Aschwanden et al. 2011), (Yang et al. 2011), (Chen & Chiu 2006), (Turner & Penn 2002).	Built environment Transportation modes in the region Study's geography	simulation space's structure
31	Bicycle	(Aziz et al. 2018), (Zellner et al. 2016)		
32	Public transportation (taxi, bus, BRT)	(Abel & Faust 2020), (Lemoine et al. 2016), (Zellner et al. 2016), (Yang et al. 2015), (Yang et al. 2012)		
33	Personal car	(Abel & Faust 2020), (Lemoine et al. 2016), (Zellner et al. 2016), (Yang et al. 2015), (Yin 2013), (Yang et al. 2012)		
34	Boundary of the congestion charge zone	(Filomena & Verstegen 2021); (Yang et al. 2020), (Abel & Faust 2020), (Badland et al. 2013)		
35	Boundary of the congestion charge zones	(Zellner et al. 2016), (Jin & White 2012), (Gao 2013)		
36	The whole city	(Aziz et al. 2018), (Yin 2013), (Jin & White 2012), (Aschwanden et al. 2011)		
37	Boundary of two or more cities	(Filomena, Manley & Verstegen 2020), (Omer & Kaplan 2017), (Omer & Jiang 2015)		
38	Urban square	(Hu et al. 2017), (Asriana & Indraprastha 2016)		
39	Virtual	(Garcia et al. 2018), (Lemoine et al. 2016), (Yang et al. 2012)		
40	Cognitive maps	(Yang et al. 2020)		

Table 3 Extraction of concepts relevant to the agent categories.

No.	concepts	Sources	Sub category	category
41	Pedestrians, citizens or work population	(Filomena & Verstegen 2021); (Filomena, Manley & Verstegen 2020); (Abel & Faust 2020), (Garcia et al. 2018), (Aziz et al. 2018), (Omer & Kaplan 2017), (Hu et al. 2017), (Lemoine et al. 2016), (Asriana & Indraprastha 2016), (Zellner et al. 2016), (Yang et al. 2015), (Badland et al. 2013), (Yin 2013), (Gao 2013), (Jin & White 2012), (Yang et al. 2012), (Aschwanden et al. 2011)	human	agents
42	Food sellers	(Abel & Faust 2020)		
43	Mobility agents (e.g. public transportation)	(Abel & Faust 2020)	systemic	
44	Metric	(Omer & Kaplan 2017), (Omer & Jiang 2015)	Human and criterion-based	
45	topological	(Omer & Kaplan 2017), (Omer & Jiang 2015)		
46	angular	(Omer & Kaplan 2017), (Omer & Jiang 2015)		

Table 4 Extraction of concepts relevant to the interaction category.

No.	concepts	Sources	Sub category	category
47	function	(Yang et al. 2021), (Hanna 2021), (Filomena & Verstegen 2021), (Florindo et al. 2021), (Huang, Kimm & Burry 2021), (Filomena, Manley & Verstegen 2020),)Abel & Faust 2020(, (Aziz et al. 2018), (Garcia et al. 2018), (Garcia et al. 2017), (Elbanhawy 2017), (Hu et al. 2017), (Huang, White & Burry 2017), (Omer & Kaplan 2017), (Asriana & Indraprastha 2016), (Lemoine et al. 2016), (Zellner et al. 2016), (Omer & Jiang 2015), (Yang et al. 2015), (Fidler & Hanna 2015), (Badland et al. 2013), (Yin 2013), (Zhu et al. 2013), (Jin & White 2012), (Yang et al. 2012), (Aschwanden et al. 2011), (Yang et al. 2011), (Chen & Chiu 2006), (Turner & Penn 2002).	Agent's act	interactions
48	Functional variables and parameters	(Yang et al. 2021), (Hanna 2021), (Filomena & Verstegen 2021), (Florindo et al. 2021), (Huang, Kimm & Burry 2021), (Filomena, Manley & Verstegen 2020),)Abel & Faust 2020, Aziz et al. 2018), (Garcia et al. 2018), (Garcia et al. 2017), (Elbanhawy 2017), (Hu et al. 2017), (Huang. White & Burry 2017), (Omer & Kaplan 2017), (Asriana & Indraprastha 2016), (Lemoine et al. 2016), (Zellner et al. 2016), (Omer & Jiang, 2015), (Yang et al. 2015), (Fidler & Hanna, 2015), (Badland et al. 2013), (Yin, 2013), (Zhu et al. 2013), (Jin & White 2012), (Yang et al. 2012), (Aschwanden et al. 2011), (Yang et al. 2011), (Chen & Chiu 2006), (Turner & Penn 2002).		
49	Decisión rules	(Filomena & Verstegen 2021); (Filomena, Manley & Verstegen 2020), (Hanna 2020) (Abel & Faust 2020), (Garcia et al. 2018), (Aziz et al. 2018), (Omer & Kaplan 2017), (Hu et al. 2017), (Lemoine et al. 2016), (Asriana & Indraprastha 2016), (Zellner et al. 2016), (Badland et al. 2013), (Yin 2013), (Ga 2013), (Jin & White 2012), (Yang et al. 2012), (Aschwanden et al. 2011)		
50	Resident agent and bus agent	(Abel & Faust 2020), (Zellner et al. 2016)	Agent-agent interaction	
52	Influence of society's behavior of people's behavior	(Garcia et al. 2018), (Aziz et al. 2018), (Omer & Kaplan 2017), (Zellner et al. 2016), (Yang et al. 2015), (Yin 2013)		
53	Residents and routes agent	(Filomena & Verstegen 2021), (Filomena, Manley & Verstegen 2020), (Hanna 2020), (Abel & Faust 2020), (Omer & Kaplan 2017), (Zellner et al. 2016), (Jin & White 2012), (Aschwanden et al. 2011)	Agent-environment interaction	
54	Residents agent with transportation agent	(Abel & Faust 2020), (Lemoine et al. 2016)		
55	Human agent with the defined space by space syntax theory	(Omer & Kaplan 2017), (Omer & Jiang 2015), (Hu et al. 2017), (Asriana & Indraprastha 2016), (Yin 2013)		

Table 5 Extraction of concepts relevant to the scenario category.

No.	concepts	Sources	Sub category	Category
56	Road-distance minimisation, RD scenario	(Filomena & Verstegen 2021); (Filomena, Manley & Verstegen 2020)	Cost-based scenarios	scenario
57	Least cumulative angular change, AC scenario	(Filomena & Verstegen 2021); (Filomena, Manley & Verstegen 2020)		
58	Landscape-based scenario	(Filomena & Verstegen 2021)	Built environment-based scenario	
59	Regionalisation-based	(Filomena, Manley & Verstegen 2020)		
60	Natural and severe barrier-based	(Filomena, Manley & Verstegen 2020)		
61	Street network change	(Badland et al. 2013)		
62	Introduction of new food stores to the model	(Abel & Faust 2020)		
63	Transportation system development	(Abel & Faust 2020), (Lemoine et al. 2016), (Zellner et al. 2016)		
64	Pavement widening	(Aziz et al. 2018), (Aschwanden et al. 2011)		
65	Reduction of pedestrians' and bicycles' incidents	(Aziz et al. 2018)		
66	Development of pedestrians and bike lanes	(Jin & White 2012)		

Table 5 Cont.

No.	concepts	Sources	Sub category	Category
67	Random distribution of non-residential functions and safety levels without considering the income rate	(Yang et al. 2015)	Distribution-based scenario	scenario
68	Segmentation of the city into central regions for low-income families and outskirts for high-income families	(Yang et al. 2015)		
69	Safety improvement as approaching the downtown	(Yang et al. 2015)		
70	Non-residential function density rise as moving from outskirt to downtown	(Yang et al. 2015)		

Table 6 Extraction of concepts relevant to the validation category.

No.	Concepts	Sources	Sub category	category
72	Consistency analysis	(Omer & Kaplan 2017), (Florindo et al. 2021)	Calibration	Model Accuracy
73	Simultaneous Perturbation Stochastic Approximation (SPSA)	(Aziz et al. 2018)		
74	Change in initial values of parameters	(Garcia et al. 2018), (Lemoine et al. 2016), (Jin & White 2012)		

Table 7 Extraction of the concepts relevant to the verification category.

No.	Concepts	sources	subcategory	category
75	Applying experimental data to define agents' behavior in model creation	(Abel & Faust 2020), (Yang et al. 2020), (Yin 2013), (Jin & White 2012)	validation of conceptual model	Verification and Validation
76	Sensitivity analysis	(Abel & Faust 2020), (Garcia et al. 2018)	Operational validity	
77	Consistency analysis	(Garcia et al. 2018)		
78	Consistency of the model's output data with experimental data (e.g. consistency of average numbers of commuting to food stores in the real world with the model's output)	(Abel & Faust 2020); (Filomena & Verstegen 2021); (Lemoine et al. 2016), (Asriana & Indraprastha 2016), (Yin 2013); (Omer & Kaplan, 2017)	Data validity	
79	Logical trace of the governing rules and the model's investigation during its operation	(Abel & Faust 2020); (Filomena, Manley & Verstegen 2020)	Computer-based verification	

essential to form the structure of simulation space. If we consider ABM as a machine, the components of this machine are formed when the structure of simulation space is determined. Though, these components are not assembled and the machine does not work yet. Therefore, it is crucial to define "agents" and the interactions among them, the interactions between agent and the environment as the connector of the components and the engine in order to create the ABM and operate it. In fact, "structure of simulation space", "agent" and "interaction" create a model which shows the real world's situation and reflects its dynamicity accurately. It also reveals our abstract understanding of the real world. This is why "structure of simulation space", "agent" and "interactions" categories are shown in a major category named "basic model".

To make an ABM in order to recognize the influence of urban policies on people's tendency to walk, it is crucial to truly define those policies which lead to the environmental changes after the basic model is created. These environmental changes which appear in the form of various scenarios can be put in a major category named "disruptor" due to their disruption in the built environment.

After the creation of the basic model and the disruptor, it seems essential to evaluate how the model's work which is done through calibration and V&V (Tables 6 and 7). Because these two steps require model operation and some other parameters' changes, these two categories are considered in a more major category named "implementation".

To define a coherent framework for the ABM in order to comprehend the environmental policies' influence on people's tendency to walk, the major categories of "basic model", "disruptor" and "implementation" were considered as the main components of the final framework.

5 Synthesis of Translations

Considering the function and relationship between major categories, categories and Sub categories found in previous sections, a comprehensive framework is created in order to apply ABM to investigate the influence of urban policies on people's tendency to walk (Figure 3).

This model is made of three basic elements. First element is "basic model" which consists of three categories: "simulation space structure", definition of "agent" and "interactions" which are formed the modeling input data.

To create simulation structure, some demographical features such as number of families, number of employed people (Aziz et al. 2018), socioeconomic status (e.g., Zhu et al. 2013; Jin & White 2012), etc. need to be defined. "Built environment" is another component of simulation space structure. Definition of the built environment can be considered the most significant sub category to create simulation space, because it is the bedrock of performing urban development policies. "Street network" is considered the main feature of the built environment (e.g., Omer & Kaplan 2017; Zellner et al. 2016). Street network works as the connector between origin and destination. Origin is considered to be the living place and destination can be different depending on the goal of each research. When improving of walking status is studied, it means that citizen tend to different transportation mods besides walking mode such as public transportation or personal cars, and due to various reasons, researchers are interested in walking improvement such as public health improvement (Bauman et al. 2002). In this end, the available modes of transportation in the region need to be carefully defined first. The other component of simulation space is to determine the under-study geography. This geography can be considered into three forms real (e.g., Aziz et al. 2018; Omer & Kaplan 2017), hypothetical (e.g., Lemoine et al. 2016) and cognitive (e.g., Yang et al. 2020).

After the simulation space structure in the basic model, agents need to be defined. Findings reveal that human agent, i.e. citizens, pedestrians, workers (Aziz et al. 2018; Garcia et al. 2018) and/or food sellers (Abel & Faust 2020) have always been defined as agents. Though, depending on the goal of study, non-human agents such as transportation system (Abel & Faust 2020) can also be implemented. Therefore, if it is possible to define function, parameter and behavioral rules for everyone, it can be considered as an agent. After determining agents in modeling process, determination of agents' interactions to each other as well as the environment is of great significance. Findings demonstrated that in macro scale studies, these interactions are well-defined, though, in micro scale studies, they are being ignored. After the definition of "agents' interactions", "agent" and "structure of simulation space", the basic model is created.

Basic model shows the current behavior of the agent in the current environment. To recognize the efficiency of the agent's future situation in the new environment (the environment which is made of the disruption in the available built environment), it is crucial to replace the current built environment with the new environment in the basic model.

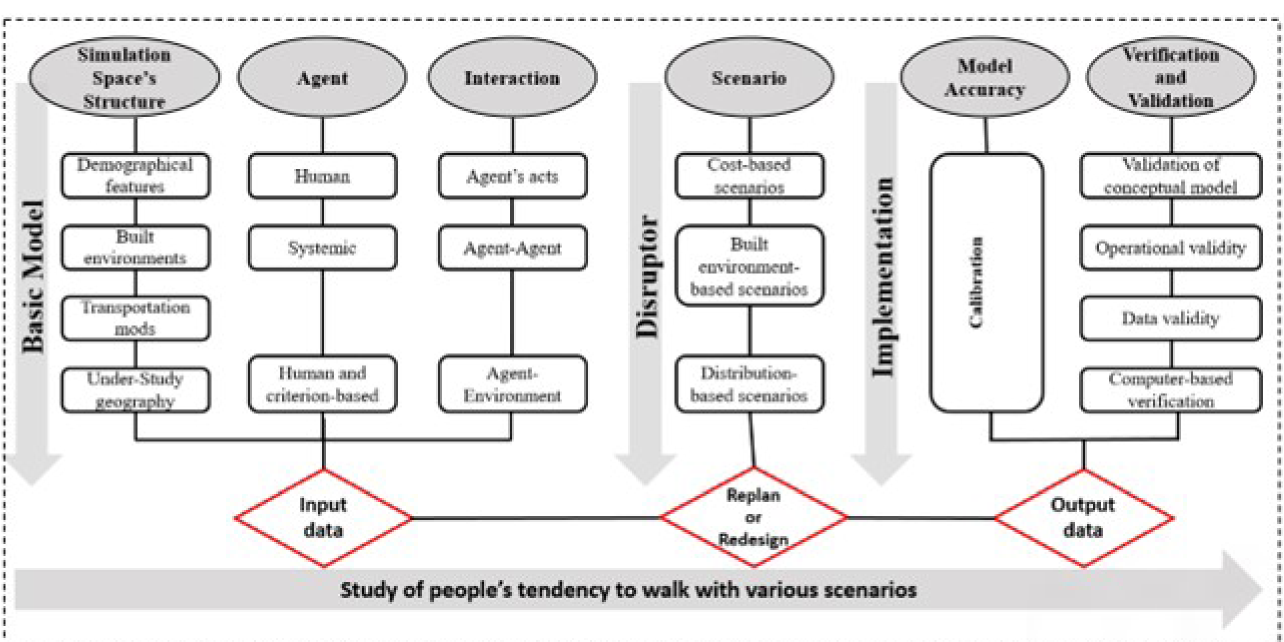

Figure 3 The comprehensive framework to apply ABM to investigate the influence of urban policies on people's tendency to walk.

Therefore, after the basic model, it is necessary to care about disruptor as another element.

Disruptors are defined as various scenarios. Scenarios are put into three categories. Some scenarios are named "cost-based" because they mean to minimize the number of influential items on people's tendency to walk. These scenarios, for example, sometimes mean to minimize the distances (Filomena & Verstegen 2021) (Filomena, Manley & Verstegen 2020) or minimize the total angular changes (Filomena & Verstegen 2021) (Filomena, Manley & Verstegen 2020). Meanwhile some other scenarios are defined to disrupt directly and generally in the environment called "built environment-based scenarios, for example, pavement widening (Aziz et al. 2018). Besides, the form of environment is considered defined and fixed in some scenarios and the environment's function changes in order to improve the level of tendency to walk (e.g., Yang 2015). These scenarios are called "distribution-based scenarios". Generally speaking, the environment is replanned or redesigned partially or wholly in this step according to each scenario. Replacing the redesigned environment in the basic model, the situation is suitable to compare people's walking behavior with the current environment.

Model implementation is another main element in the designated conceptual framework. The most significant issue in model implementation is the capability to evaluate the validity of findings. In this end, the issues of model accuracy and V&V are of great significance. Normally, model accuracy and V&V are practiced in two different domains (e.g., Omer & Kaplan 2017). model accuracy talks about calibration (Lemoine et al. 2016) which can be practiced in different ways. V&V has also got various dimensions which are divided into four sub categories of "validation of conceptual model", "operational validation", "data validation" and "computer-based verification". Experimental results from the survey are used to validate the conceptual model (Yin 2013). Through analyses of sensitivity and consistency, operational validation is done. As the most significant part of this step, data validation evaluates the model's output and compares it with real world's data outside the calibration domain (e.g., Asriana & Indraprastha 2016). Computer-based verification traces the logical relationships in the model while the model is being performed (Abel & Faust 2020).

6 Discussion

Findings of this study are similar and different with the ones of other studies. In all studies, structure of simulation space and agents are clearly determined. In most of them, common logic governs the relationships between the components and this logic demonstrates the interactions between the agents as well as the agents and the environment (Abel & Faust 2020; Filomena & Verstegen 2021; Aschwanden et al. 2011). In some macro scale studies (e.g., Yang et al. 2015), the interactions of agent-agent and agent-environment is being considered. Though, the researchers in some studies with micro scale (i.e., neighborhood), for the purpose of simplification, are being ignored them (e.g., Badland et al. 2013) which has been criticized. Urban neighborhoods are considered as a small division of urban divisions. Therefore, they are way too smaller than bigger urban divisions such as districts. This is why they are experiencing more social interactions in comparison with macro urban scales (e.g., districts) (Sharifi 2019). Therefore, it seems that unlike what has happened in researches to now, shrinking the geographical scale of under-studying areas leads to the rise of sensitivity in considering agent-agent and agent-environment interactions.

In order to improve the level of tendency to walk, disruptors that are defined as various scenarios are implemented as an essential element in agent-based modeling. In fact, they define options which can improve people's tendency to walk, though, these scenarios are not defined in some studies. Their main goal in modeling is to predict the level of walking and the current situation as well, but not to change the level of walking using environmental changes during the time (e.g. Omer & Kaplan 2017; Hu et al. 2017). Then, if modeling aims to determine the appropriate principles for tendency to walk improvement, logical scenarios' definition will be an essential part of ABM.

After the implementation of ABM, its results can be seen, though, the challenge of the findings' validity is inevitable. To overcome this drawback, various studies tried to calibrate, verify and validate the designed modeling in order to adapt the model's output with the real world (e.g., Omer & Kaplan, 2017). Due to unavailability of the real world's information, though, some studies announced this step as a constraint in their investigation and ignored it (e.g., Hu et al. 2020; Badland et al. 2013). The findings of calibration- and V&V-free model are not suitable for citation and this is only modeling experience which is suitable for the purpose of citation.

7 Conclusion

Conceptual frameworks create a structure to adjust abstractions systematically and then develop as the research develops. During the last two decades, numerous studies have been dedicated to investigate the influence of urban policies on people's tendency to walk using an agent-based approach. Therefore, it is considered to be the right time to meta-synthesize experiences and aggregating data into a unit in order to create a comprehensive framework to use in ABM studies in future. This is why this study emphasizes the experiences of the past two decades about the influence of urban policies on people's tendency to walk using an agent-based approach in order to form novel understanding about a comprehensive conceptual framework for these researches. Walsh and Dawne's (2005) meta-synthesis technique is applied to analyze and provide this framework. To validate the model, feedback of a group of 8 professionals was collected in all steps of meta-synthesis and then judged by a group of 2 academic experts as the referees. The feedback was implemented during the model creation.

This study revealed that an appropriate framework to study the urban policies on people's tendency to walk using an agent-based approach includes three crucial elements, i.e., "basic model", "disruptor" and "operation" process.

"Basic model" depicts the abstract level of the reality which has been considered by the modeler and is created using field and library data (data relevant to simulate space, agent's behavior, interactions of agent-agent and agent-environment). To create the basic model, it seems essential to define clearly the structure of the simulation space using the following features: geography, built environment, regional transportation modes and the study's geography.

Then, agent needs to be determined and formulate agent-agent and agent-environment interactions. Findings showed that micro scale of the under-study geography cannot be a determinant to ignore agent-agent and agent-environment interactions' definition. After the definition of simulation space structure, it is fundamental to determine various disruptions in the basic model in order to improve people's tendency to walk as the "cost-based" scenarios, "built environment-based" scenarios and "distribution-based" scenarios.

As shown in the last element of the recommended framework, after the creation of the agent-based model, it is essential to assess the findings' validity as a key step to implement the modeling's findings. This purpose was done initially through make accuracy of model by model's calibration in some specific areas of the study. After calibration, data validation should be implemented inside the study area outside of the domain where the model was calibrated in order to evaluate the model's validation. To make the model highly verified and validated, it is recommended to use surveying data in the model, conduct sensitivity and consistency analyses and trace the relationships in the model which is being run on a computer. Without verification and validation, modeling experience is only suitable for citation and then, we must be cautious in applying findings.

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Author contributions

Masoud Zamanipoor: conceptualization; formal analysis; methodology; validation; writing-original draft; writing – review and editing; visualization. **Mohammad Rahim Rahnama:** methodology; validation; writing – review and editing; supervision. **Mohammad Ajza Shokouhi:** methodology.

Conflict of interest

The authors declare no potential conflict of interest.

Data availability statement

All data included in this study are publicly available in the literature.

Funding information

Not applicable

Editor-in-chief

Dr. Claudine Dereczynski

Associate Editor

Dr. Silvio Roberto de Oliveira Filho

How to cite:

Zamanipoor, M., Rahnama, M.R. & Shokouhi, M.A. 2023, 'Create of a conceptual framework for the use of an agent-based modeling in urban studies with an emphasis on the walkable city', *Anuário do Instituto de Geociências,* 46:53866. https://doi.org/10.11137/1982-3908_2023_46_53866