DOI: 10.38027/ICCAUA2021161N9

The Influence of Diverse Building Height and Building Coverage Ratio on Outdoor Thermal Performance in Hot Climates: A Review

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Abstract
Although urban form can significantly affect outdoor climatic conditions, urban planners do not sufficiently consider such impact while designing new urban communities in Egypt. Proper configuration of urban blocks can make positive contribution to alleviating the adverse effects of urban climate. However, new cities are constructed to be formed from lowly dense buildings that overlook curvilinear streets networks without considering orientation. Furthermore, the use of unified building heights, spaces of low aspect ratio and high sky view factor lead to less shaded areas. The research at hand aims to shed light on literature that discuss urban form parameters and their relation with outdoor spaces thermal performance in warmer climates. These studies are classified, analysed and compared in terms of the investigated parameters, and the methodological approach of each study. The findings can help defining gaps in the existing literature while providing holistic overview of the current state of art.
Keywords: Urban geometry; Standard deviation of height; Building coverage ratio; outdoor thermal comfort; Energy consumption; New cites expansions; Hot arid climate.

1. Introduction

Climate change is a worldwide problem especially with the rise in population and urbanization sprawl (Aboulnaga & Mostafa, 2019). One of the negative effects of climate change is increasing the frequency and intensity of heat waves resulting in higher air temperature, ends up creating many difficulties such as, human health threating as well as thermal comfort deficiency. Thus, rise in the percentage of deaths globally when exposed to extreme heat conditions for a long time (Norton et al., 2015). While designing the urban plan in new urban communities unfortunately thermal comfort plays a secondary roll by planners (Krüger et al., 2011). Urban planning has an enormous impact to the local microclimate, which in end result affect thermal comfort, vibrance of liveability of public space [Street, gardens] (Bourbia & Boucheriba, 2010). In order to be eco-friendly this urban development requires special criteria from decision makers and urban planners, for urban design in such a harsh climate that should passively ensures good ambient conditions (Sustainable Development Strategy (SDS), 2016). In particular, outdoor spaces throughout residential areas which are crucial for sustainable cities to maintain high quality of life (Mahmoud, 2019). The urban form ,height, ways of placing and spacing of the buildings structures noticeably affect the amount of received an emitted radiation on the public spaces particularly in hot desserts with direct solar radiation(Shalaby, 2011).So, they must be designed in such a way that their thermal performance can be enhanced an decreasing indoor energy consumption (Stone & Norman, 2006). The increased energy demand arising by using air conditioning adversely affects the built environment by the Urban Heat Islands.

In Egypt, new urban communities and cities under construction or future extensions constructed are not compatible with its hot dry climate (Mohamed Fahmy & Sharples, 2008) especially social housing projects. New cities such as New Cairo, New October and cities in Upper Egypt go through the following: Commitment to unify a prototype used in new urban cities for social housing (ground plus five floors) for rapid execution and fixing the cost, without taking in consideration the difference in streets width and orientations which effects the quality of life for social housing residence. Resulting into higher sky view factor and lower aspect ratio values leading to less shaded areas. Urban planners preferred curvilinear street networks as an aesthetic scene, which no longer set up a dominant orientation. Therefore, these factors have great influence on the microclimate and pedestrian thermal comfort.

Street canyon considered one of the main geometrical components of the urban form as it regulates the intensity of solar radiation absorbed and re-emitted by buildings. It is also directly linked to the outdoor activities of the residents (Shishegar, 2013). Accordingly, the study attempts to discuss how prior literature studied the impact of urban geometry parameters on pedestrian thermal performance. In this context, a considerable amount of literature managed to come up with knowledge gained that could together formulate a holistic model of urban form. Still what is not extent in these studies is the combination of manipulating building heights, building coverage ratio as well as its orientations together could influence mitigating outdoor thermal comfort for pedestrians in an urban block.

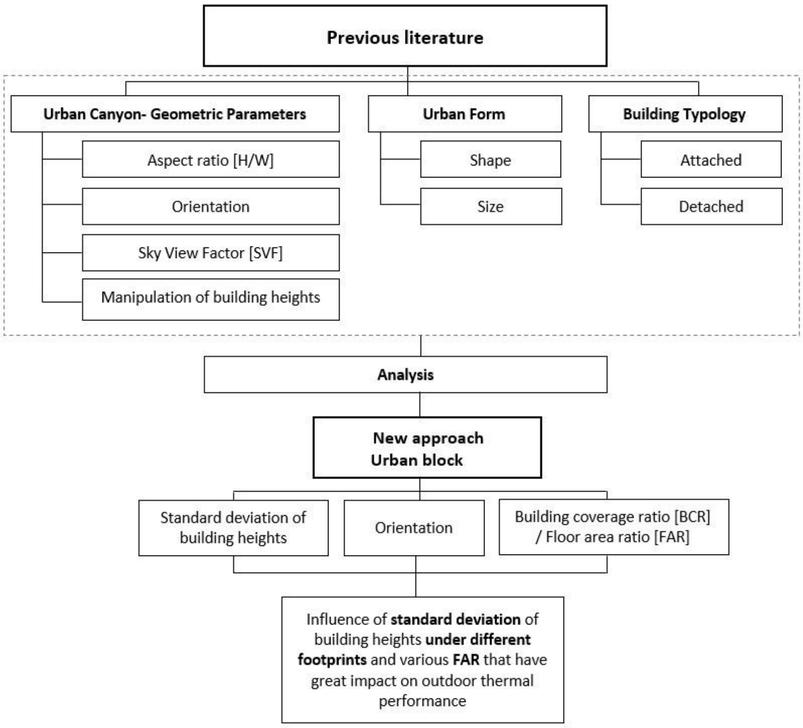


Figure 1. Structure of the Study (Developed by Author).

2. Material and Methods

Prior studies recently focused not only on enhancing the indoor thermal comfort but also the outdoor microclimate and pedestrian thermal performance in street canyons (Fahmy & Elwy, 2016). A comprehensive review for literature was performed on outdoor thermal comfort mitigation based on journal articles and conference papers from more than 28 study in warm climates globally and Egypt as well. Pedestrian thermal comfort, hot dry climate, urban geometry, Numerical simulation and Envimet were the mostly used keywords that facilitated in collecting the data. This review found that the previous studies could be classified into three categories that will be discussed and analysed a) urban canyon geometrical parameters , b) urban form and c) building typology influence on the climatic parameters such as [air temperature, wind direction, wind speed, air humidity] in warm cities . Figure 1 illustrates the framework of the study in order to consider the implications of different urban form parameters on local microclimate and thermal comfort. The outcomes will assist in identifying gaps in the available studies and introduce new simultaneous examinations of urban geometry parameters. These studies were performed either by simulations (Ali-Toudert & Mayer, 2006) or measurements (Johansson, 2006).

3. Results

Depending on the results obtained from prior literature, the study investigated how urban planning affects the pedestrian thermal sensation in outdoor areas and local microclimate that significantly enhance the quality of life for people in warm climates.

3.1. Influence of Canyon Orientation and Aspect Ratio on Thermal Comfort

An increasing body of research seeks the contribution of solar orientation and aspect ratio of a street design geometry towards the establishment of a convenient thermal sensation of pedestrians. In Ghardaia, Algeria two symmetrical buildings were simulated in a street canyon 8 meter width for aspect ratio [0.5 , 1 , 2 , 4] in EW , NS. Afterwards, buildings with aspect ratio 2 simulated in the four solar orientations. Results reviled that with the increase of aspect ratio the air temperature decreases for the EW, NS orientations. In addition, H/W 0.5 was the warmest for EW canyon, thus to overcome this, shaded structures are recommended. Besides, the NS orientation when aspect ratio is greater than 2 it anticipate lower PET values. Moreover, for the last aspect ratio, NE-SW and NW-SE solar orientations contributes to superior comfort conditions (Ali-Toudert & Mayer, 2006).

In this aspect (Rodríguez Algeciras et al., 2016) in Camaguey-Cuba, old town questioned the peak PET values spatial distribution along daytime in addition to aspect ratio and street orientation within the street canyon. Which is essential for the selection of the most desirable spaces according to pedestrian thermal requirements.

On this regards, various urban canyons conducted for simulation using RayMan model. Consequently, input data variables taken from airport weather station in Camaguey from 2001-2012, such as, air temperature, wind speed, relative humidity, vapour pressure, solar radiation, and sunshine hours taken with a resolution of 1hr. Besides, symmetrical urban street canyons of 9 m width and 380 m long tested with different solar orientations [N-S, NE-SW, EW, NW-SE] among various aspect ratios [0.5, 1, 1.5, 2, 3, 4, 5] respecting the urban street settings. Next, to provide a clear understanding for diurnal evolution of microclimate and thermal comfort on pedestrian level , street canyons are subdivided into five equal sections [points: A , B , C , D and E] with 1.5 m horizontally apart for better spatial resolution , as shown in fig 2. In addition to point out variation between the centre and the edges of a street canyon, measurements taken from 6 am to 8 pm. This study preformed during summer and winter in Cuba for buildings around the urban canyon presumed that they are made of brick [albedo o.3].In fact for all models, the wind velocity kept constant according to results obtained from weather station. Results indicated that during nocturnal hour's thermal performance very close due to the lack of solar radiation. On this scene, at midday two extreme cases generated, which are the N-S and E-W orientations with lowest and highest Physiological Equivalent temperature [PET °C] values. N-S orientation leads to less heat stress for high aspect ratios [2-5 H/W] especially after 2 pm, because streets are shaded, max PET 35°C occurs only at one hour at midday. However, the N-S streets seem globally as unpleasant as E-W orientation for low aspect ratios [0.5-1], with maxim PET values on the west side point E, at the midday. Besides, E-W orientation is extremely uncomfortable for low aspect ratios especially 0.5 reaching the peak PET 36.2 °Cat one o'clock. The only comfortable zone is at the south facing side of the street point A. One of the main mitigation strategies is the management of green areas to provide shade to pedestrians for the other points of the street. Noticeable pedestrian performance for aspect ratio around 1, both during summer and winter especially when linked to intermediate orientations NE-SW and NW-SE, similar to results found by Ali Toudert 2006,when increasing aspect ratio leads to 24 k enhancement to PET values. Next, 1.5 H/W was most favourable in summer with respect to adding tress in E-W orientation. For deeper canyons H/W> 2 seem to be suitable for PET values although it leads to low wind velocities. Therefore, E-W not recommended in deep canyons. In line with the geometrical parameters of urban canyons, E-W streets need very cautious and precise interventions (Rodríguez Algeciras et al., 2016). Finally, previous results is similar to results found by Ali Toudert & Mayer (2006) study for hot dry climate in Algeria. Last but not least, other studies focused on the effect of SVF in addition to street orientation and aspect ratio.

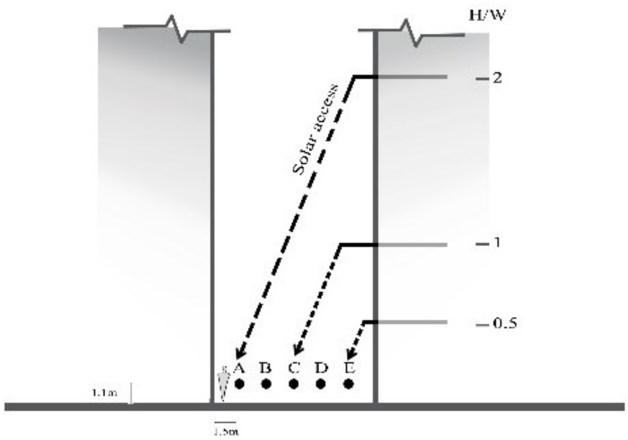


Figure 2. Street canyons subdivided into five equal sections (illustrated by author based on Rodríguez Algeciras et al., 2016).

Furthermore, considerable insights came up from another study, investigating various orientations and aspect ratios combination in the hot eastern desert of New Cairo, Egypt street canyons, in order to expand diurnal thermal comfort as well as to alleviate nighttime urban heat island. In addition, two orientations [N-S, EW] tested along H/W ranges from 1 to 5 using ENVI-met v3.1. Results in the hottest summer day indicated that for north south, street the most preferable H/W is 3 not less to offer better thermal comfort conditions for pedestrians in the morning hours, and not more than 3 to mitigate urban heat island effect during night hours. Secondly, recommended aspect ratio 1 for E-W oriented street (Shafey, 2018).Table1 reviews the results obtained by prior literature discussed in warm climates produced by various aspect ratios and solar orientation with respect to symmetrical street profiles.

3.2. Impact of Urban Geometry (H/W, orientation and SVF) on Urban Climate

In the response to microclimate, Bourbia & Boucheriba (2010) discussed the impact of street geometry [H/W, SVF, orientation] on the canyon climate [air and ground temperature] in Constantine, Algeria. The study was set in the downtown featured with narrow street canyons with average five floors without vegetation. Next, seven stations during summer were chosen for the experiment, measurements were considered in different orientations, aspect ratio which ranges between 1 to 6.7 and sky view factor [SVF] scale between 0.076 and 0.58. SVF discovers the amount of solar radiation gained on a surface which range between zero and one, and as a result, the variation of temperature values reached at the site (Chapman & Thornes, 2004).Air temperature collected using wireless weather stations, and thermos couple with probe measured ground temperatures. Moreover, weather stations used and located twelve km away from the site this anticipated the UHI phenomena. The research implies that the difference of air temperature between the seven stations varies about 3℃ to 6℃ between the urban canyons and open site field during night. The depletion of urban radiation is thus highly linked to sky obstruction, the less apparent the air to the sky, prolong cooling and heating along the day. Therefore, it is clear that the SVF has great impact on thermal comfort and urban microclimate, this relation appears in table 1. The station with the greatest aspect ratio and lower sky view factor revel better results (Bourbia & Boucheriba, 2010).While this study focused on downtown, on the other hand, there are studies focused on investigating whether traditional compact urban forms or the contemporary modern urban form are preferable in accordance to thermal preferences.

3.3. Impact of Building Typology on Microclimate and Thermal Performance

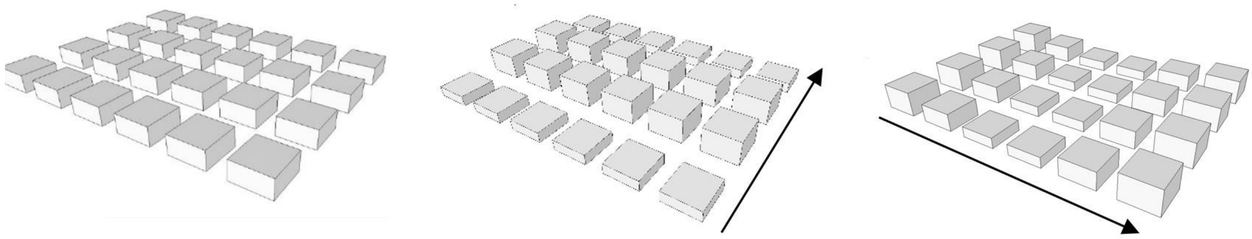
A study dealt with the impact of the existing regulations of the urban planning on the microclimate in a hot dry climate in Damascus, Syria. ENVI MET 3.0 simulation program used to compare three residential zones in modern and old area of Damascus. The first zone for detached buildings with H/W 0.31 with width 32 m, the second zone also modelled for detached buildings H/W 0.83 with width 18 m in modern area. Finally, the third zone in old Damascus represents attached buildings only with H/W 2.95 with width 3.8 m. The PET index calculated for the previous zones at 1.1 m height taken at three different points in the street, one in the middle the other two on the pavement, between 7:00 and 16:00. The results emphasized that the highest PET was in the middle of the street, with maximum value 50 ℃ at 14:00 in modern zones of Damascus [detached buildings], while around 33 ℃ in old Damascus [attached buildings]. The temperature difference between the points on the pavement for detached buildings was not noticeable because of their same exposure to solar radiation. As for street surface temperature, the impact of street orientations are not decisive. Modern Damascus revealed higher temperatures than old Damascus characterized by higher H/W ratio, which means more shading is demanded. Moreover, results declared that for modern zones prescribed by low H/W, large setbacks and wide streets eventually led to detached urban form where significant portion of the buildings and streets are highly subjected to solar radiation as shown in table 1. As a result, the author focus on the importance of modifying the current regulations. For example, by decreasing front setbacks, increasing H/W and narrowing the streets. Besides, adding shading devices projected from buildings, or tress at street level, which reduced PET values from 50 ℃ to 34.3 ℃ (Yahia & Johansson, 2013).

Table 1. Table 1. Effect of Urban canyon geometrical parameters, urban form and building typology on mitigating outdoor thermal comfort.

Author	Location	Climate	Urban Patteren variables								Canyons geometrical mitigation variables		Study objective		Results
			urban form		Urban canyon- Geometric Parameters						Street Side profile				
			Shape		orientation				H/W	SVF	Symmetry	Asymmetry	Thermal comfort	Urban microclimate	
			Aligned	Zigzagging	N-S	E-W	NE-SW	NW-SE							
Ali-Toudert & Mayer, 2006	Ghardaia - Algeria	Hot and dry climate		√	√	√	√	√	0.5,1,2,4 for main oientation & 2 for intermediate	-	utilized for N-S , E-W orientations	-	√		In summer N-S revealed better results in all aspect ratios investigated. Better PET values when H/W ≥ 2. H/W 4 is preferable for intermediate orientations
Rodriguez Algeciras et al., 2016	Camaguey-Cuba	Tropical savannah climate		√	√	√	√	√	0.5,1,1.5,2, 3,4,5	-	utilized for all orientations	-	√		N-S orientation leads to less heat stress for high aspect ratios [2-5 H/W] especially after 2 pm. Point E is the best for N-S. For E-W aspect ratio > 0.5 is prefered, Point A is best for this orientation.1.5 H/W was most favorable in summer with respect to adding tress in E-W orientation
Shafey, 2018	New Cairo-Egypt	Hot arid climate	√		√	√	√	√	1,2,3,4,5	–	utilized for all orientations	-	√		For summer N-S street best H/W=3 not more or less. For E-W , H/W=1
Bourbia & Boucheriba, 2010	Constantine-Algeria	Semi arid climate	√		√	-	√	√	From 1 to 6.7	From 0.076 to 0.58	-	utilized for all orientations		√	Surface & air temerature increase by 6°C when SVF ↑ and aspect ratio ↓. At nocturnal hours , open spaces is cooler than urban spaces with 3 to 6 °C.
Yahia & Johansson, 2013	Damascus-Syria	Hot dry climate	-	-	√	√	-	-	2.95 for old Damascus and 0.31,0.83 for modern Damascus	-	utilized For old Damascus	utilized For Modern Damascus	√	√	The results emphasized that the highest PET was in the middle of the street, with maximum value 50 °C at 14:00 in modern zones of Damascus [detached buildings], while around 33 °C in old Damascus [attached buildings]

3.4. The Influence of Manipulating Building Height on Outdoor Thermal Performance

According to previous studies Emmanuel & Johansson (2006) and Ndetto & Matzarakis (2013) on the influence of canyon orientation and H/W ratio on human thermal comfort in outdoor environment for hot humid climate for example, in Colombo, Sir Lanka, results proved that asymmetrical street H/W ratio is the best configuration. As well as deep street canyons provide condition that is more favourable in summer, while shallow, street canyons offer greater solar exposure in winter. As well as, a number of studies had tested the influence of maximizing the shading effect and high/width ratio on outdoor microclimate conditions (Andreou, 2014). However the purpose of (Shareef & Abu-Hijleh, 2020) study was to explore how manipulating building heights effect outdoor thermal performance, described by outdoor air temperature and wind speed.A simulation methodology used ENVI MET 4.1 to model a pavilion form for a residential urban block in Dubai consisting of five floors with uniform height as a base case. In this sense, calibration between averages collected data using EXTECH 45170-validation tool and simulated air temperature was recorded. On this regard, the real data obtained covered air temperature for 12 hours. The instruments mounted at a level of 1.4m. Consequently, the data compared to the receptor data produced from the ENVI MET 4.1 simulation tool. There were forty-four scenarios studied against the base case to reach the best thermal performance for the selected urban block, simulated in four orientations dividing the scenarios into two groups fig 3. As for the first group, the diversity in height was implemented thought the short axis while in the second group the variation was through the long axis, preserving the H/W ratio as shown below. The built up area of the urban block and the canyon width would remain constant for all the mentioned scenarios. The result of the study indicated that for all configurations North South is the best orientation as it minimizes the outdoor temperature due to its least exposure to the solar intensity, while the worst orientation NE-SW. Moreover, the difference between the previous orientations reached 1.84 °C reflecting 5 % decrease in ambient air temperature in the base case. Besides, comparing two groups revealed that the short axis results obtained better outdoor thermal performance due to effective height variation than the gradual variation implemented along the long axis. Noticeable influence on increasing wind speed and the decrease of outdoor temperature achieved when highest building modeled in the middle of the urban block. For example, air temperature decreased by 1.10 °C in the first configuration while 0.90 °C in the second configuration in the NW-SE orientation (Shareef & Abu-Hijleh, 2020). This phenomena was reported by (Priyadarsini & Wong, 2005) and (Chan et al., 2001).



Base Case Short direction long direction

Figure 3. Scenarios (illustrated by author based on Shareef & Abu-Hijleh, 2020).

3.5. Impact of urban form on Physiological Equivalent Temperature [PET]

The study focused on how urban form [shape and density] impact on PET at pedestrian level in new urban cities expansion. Moreover, aiming to suggest guidelines to ameliorate New Aswan City's planning extension. While earlier studies adopted similar objectives through a standardized parametric analysis for different scenarios [H/W, SVF], this study pursued different path. Firstly, a quarter from New Aswan city with curvilinear urban form selected and calibrated via ENVIMET after taking measurements from New Aswan University. Next, four existing quarters of different urban form from Great Cairo compared with it under the similar climatic conditions of New Aswan. The first quarter taken from Basilica with iron grid shape. Secondly, from Mary land quarter which feature a zigzag urban form. Thirdly, Down Town quarter with radial shape. The Fourth quarter taken from Mohndessen with zigzag urban form and irregular street pattern. This method assisted together to investigate how various urban form relevant factors are correlated with PET alteration at multiple spatial scales (Galal et al., 2020).

Results revealed that the highest average PET and air temperature values found in New Aswan, while the lowest in Mohndessen. Thus, different urban forms led to 8.14 °C difference in average PET values. Furthermore, measurements within the urban block indicated that blocks within Basilica had the highest PET 49.91 °C, with FAR 1.39, while lowest PET in Downtown 41.77 °C, FAR 5.91. This research recommends FAR 7.6 and enclosure fraction 90% using multiple regression analysis to reach 41°C as an average PET value for hot arid climate with H/W approximately 3 and orientation N-S, NE-SW, NW-SE (Galal et al., 2020). Finally, this paper was not focused on the repetitive clusters of social housing as much as it focused on abstract urban environment.

4. Discussion

As it is mentioned in previous section, the studies concluded that the FAR and enclosure fraction are the most influential when designing urban blocks, however the most impactful while designing the streets are orientation and aspect ratio. It is realised that the NS orientation with aspect ratio greater than 2 and not more than 3 have the best impact on local microclimate and thermal stresses. In case of EW orientation, aspect ratio 1 and not less than 0.5 is recommended also it is preferable to be accompanied by vegetation. Furthermore, intermediate orientations aspect ratio should not exceed 4 in order to avoid heat trap.

The majority of the reviewed studies focused on urban canyon, nevertheless there is no prevalence of the same degree for studies that focus on urban blocks. In spite, it is considered to be spaces that form urban environment used by social housing residence. In addition, simultaneous examination of urban geometry parameters such as standard deviation of building heights under different foot prints and various FAR that have great impact on outdoor thermal performance are limited. In local studies in Egypt, there was limited concern to enhance and ameliorate the microclimate for social housing patterns that is now applied by the government in new urban communities. However, it is assumed that there will be a great construction for social housing schemes, as the government intends to build hundred thousands of apartments annually in one hand , and regenerate informal settlements on the other hand (New Urban Communities Authority of Egypt, 2021).

5. Conclusions

The paper demonstrates the findings of extensive measurements obtained by comparing prior studies, which exposed the shortcomings of the existing planning legislation in warm cities. Most of reviewed studies focused on improving microclimate in street canyons which acknowledged that the best solar orientation is the North south with aspect ratio bigger than 2. Shading is known to be the key parameter that has great impact on the thermal conditions in hot climates (Emmanuel et al., 2007).This can be achieved by increasing the aspect ratio and lowering SVF as well as adding tress. Increasing the FAR and BCR can make better shading.

More studies are needed to focuses in mitigating outdoor thermal comfort within an urban block by making variation in building heights under different FAR and increasing BCR as a new approach for mitigation. In order to enhance the local microclimate of the repeated blocks constructed in social housing communities in Egypt.

Acknowledgements

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflict of Interests

The authors declare no conflict of interest.

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