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Climate-Responsive Design Guidelines for Urban Open Spaces in Hot Arid Climates

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ABSTRACT: Urban heat is a common challenge for many cities, especially in hot arid climate regions as they experience high average air temperatures compared to other climate types. Hot arid cities also have common climate issues such as drought and flash floods. Climate-responsive design can be implemented by spatial designers (i.e., landscape architects and urban designers) to address these issues and, hence, improve outdoor thermal comfort. Design guidelines can assist spatial designers when designing urban open spaces in hot arid. The goal of this study is to develop climate-responsive design guidelines for urban open spaces in hot arid regions. Two methods were employed to fulfil the goal of this study: 1. A systematic literature review; 2. Research for Design. The results show that different street aspect ratios and orientations require careful selection of climate-responsive design strategies in urban open spaces in hot arid cities to provide daytime and night-time outdoor thermal comfort. Also, it is essential to incorporate common climate issues such as drought and flash floods in climate-responsive design guidelines. Presenting design guidelines spatially was considered useful to communicate these guidelines to spatial designer.
KEYWORDS: Climate-responsive design, Design guidelines, Urban open spaces, Hot arid climate

1. INTRODUCTION

Urban heat has been acknowledged as a hazard to health and wellbeing as well as outdoor thermal comfort of urban populations. Some climatic regions are more severely affected by the impacts of urban heat than others. An example is hot arid climate regions, also known as BWh according to Köppen-Geiger climate classification (Fig.1) [1], where temperatures are per se extremely high in summer. In addition, many of the growing cities worldwide are located in hot arid climate regions [2].

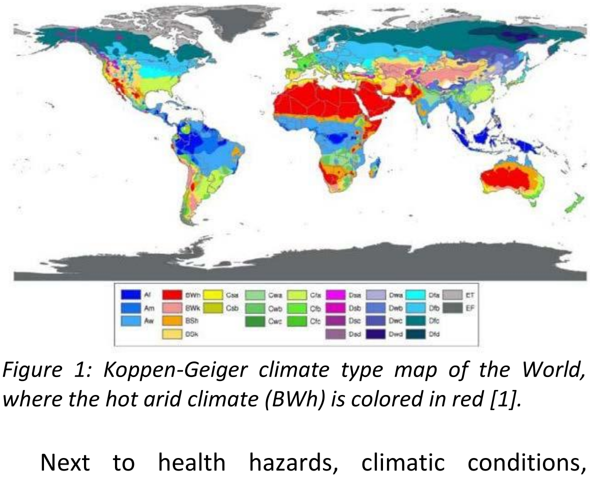


Figure 1: Koppen-Geiger climate type map of the World, where the hot arid climate (BWh) is colored in red [1].

Next to health hazards, climatic conditions, especially when harsh, have an impact on residents' engagement with urban open spaces and in hot arid climates, people often avoid urban open spaces during noon and afternoon hours because of high solar radiation and air temperatures. This is a suboptimal use of urban open spaces, which should thus be designed to minimize the impacts of heat stress especially for extreme heat periods. Apart from that, it is essential to consider other common climate challenges in hot arid climates such as drought and flash floods.

Climate-responsive design can be implemented by spatial designers (i.e., landscape architects and urban designers) to address these issues and, hence, improve thermal comfort and safety conditions. Design guidelines can assist spatial designers in this task for urban open spaces in hot arid climates by providing guidance based on scientific knowledge.

A limited number of studies has been conducted for urban open spaces in hot arid climates and the information is scattered. Still, some studies do provide valuable design strategies to cope with heat stress in these climatic regions. Synthesizing this knowledge is needed for two reasons: (1) to have a holistic view on existing climate-responsive design guidelines for urban open spaces in hot arid climate regions; (2) to develop and test new design guidelines for these regions.

Motivated by these needs, this paper addresses the question: which climate-responsive design guidelines can be implemented in urban open spaces in hot arid climates?

The aim of this study is to contribute to filling in the knowledge gap on climate-responsive design in hot arid climate regions by presenting climate-responsive design guidelines extracted from a systematic literature review on climate-responsive design in urban open spaces in hot arid climate regions.

2. METHODS

Two methods were employed to fulfil the goal of this study:

- A systematic literature review was conducted using the Preferred Reporting Items for Systematic Review Recommendations (PRISMA) method [3]. The Google Scholar search engine was used to search for relevant studies, and 17 studies were found out of 2815.
- Research for Design (RfD). Because this research approach helps to inform design to improve its quality [4], RfD was used to generate climate-responsive design guidelines not distilled from the literature review.

Eventually the design guidelines resulting from this process were synthesized and represented spatially for recurrent urban open spaces in hot arid climate regions.

3. RESULTS AND DISCUSSION

3.1 Systematic literature review

The literature review identified six main types of climate-responsive design interventions for hot arid climate cities. These design interventions are urban form, shading devices, vegetation, water elements, materials, and combined design interventions.

3.1.1 Urban form

Urban form has been addressed in previous studies as having a significant impact on microclimatic parameters and outdoor thermal comfort through changing shade patterns and wind directions. Urban form parameters include aspect ratio (H/W), street orientation and sky view factor (SVF).

It was found that low H/W ratio (e.g., 0.42) increases the temperature and the intensity of the urban heat island due to the high solar exposure [5]. A low H/W ratio does not provide shade [6] and H/W = 0.5 requires shading strategies at the street level [7]. Deep street canyons (H/W ≈ 2) in high-density neighbourhoods were found to be cooler and more humid compared to those in lower H/W values [8]. Street canyons with H/W values between 1 and 2 can be a good compromise as they provide shade and prevent the trap of reflected solar radiation [9].

The North-South (N-S) orientation is reported as the providing the best conditions for thermal comfort as exposure to direct solar radiation is limited. In some cases, the north-orientated urban open spaces are preferred for ventilation as the prevailing wind direction is parallel [10]. The N-S, North-eastern-Southwestern (NE-SW) and North-western- South-eastern (NW-SE) orientations show similar physiological equivalent temperature (PET) patterns [7]. NW-SE oriented streets presented reduced PET values in two case studies in Egypt [11,12] and provided lower air temperature and higher values of humidity [8]. A study in Egypt showed that the most thermally uncomfortable orientations were East-West (E-W) and NE-SW although the NE-SW orientation was slightly better [12].

High SVF values close to 1 in urban open spaces enhance air flow [10,13]. In turn, in low SVF spaces wind speed is lower [10] and, therefore, placing horizontal shading elements (e.g., shade devices or trees) should not hinder the airflow [14].

3.1.2 Shading devices

In general, shaded spaces have lower PET values compared to non-shaded spaces [15] and are more likely to be used. Shading devices can provide shade when buildings do not provide enough shade for pedestrian, especially at midday and afternoon hours. However, placing too many shading devices could hinder night-time time heat release and cause thermal discomfort at night. A possible solution is placing retractable shading devices to accelerate heat release [16].

3.1.3 Vegetation

Vegetation – trees in particular - is one of the most effective heat mitigation strategies. Trees can minimize thermal discomfort and provide cooling effects through evapotranspiration and shade. Trees in streets with H/W ratio of 1 can provide good microclimates similar to deep H/W ratio (H/W=2) streets [8].

Planting small and large trees can similarly provide adequate shade for people. However, large trees can prevent the release of heat at night, leading to a warmer air temperature [17]. This is more likely to happen in narrow streets and small squares. Thus, it is essential to maintain enough spaces around trees for ventilation and night-time heat release.

Drought is a common climate challenge in hot arid climates and can increase stress and mortality risk for trees. Also, trees need adequate amount of water to grown and survive. Thus, implementing stormwater retention strategies can provide water resources for irrigation, and mitigate the risk of flash flooding.

3.1.4 Water elements

The use of water elements can provide cooling effects in urban open spaces. Water mists, for example, can lower the main radiant temperature by 8.2 °C and the air temperature by an average of 3.5 °C, and that can lower the PET value [18]. However, it is not wise to use water elements as there are environmental and cost concerns because many hot arid climate regions suffer from drought and water scarcity.

3.1.5 Materials

The use of high-albedo materials in urban open spaces has positive and negative impacts. High-albedo materials can lower the daytime air temperature but can increase the night-time air temperature [19]. High-albedo materials can increase the mean radiant temperature values [20], and a possible solution is to shade high-albedo materials [9]. To this end, the use of materials, especially high-albedo materials, is not effective as other climate-responsive design interventions in hot arid climates.

3.1.6 Combined design interventions

Previously mentioned climate-responsive design interventions can be combined to provide better cooling effects and outdoor thermal comfort. The shade of trees and buildings can lower the predicted mean vote (PMV) [20]. While the shade of trees and shading devices can provide low mean radiant temperature and PMV [21].

Overall, the combination of design interventions can enhance the cooling effects in urban open spaces in hot arid climate cities and need to be considered to develop effective design guidelines.

3.2 Research for Design (RfD)

Based on the outcomes of the literature review, some design guidelines were developed with the RfD. These design guidelines take into account effective daytime and night-time heat mitigation strategies (Fig.2).

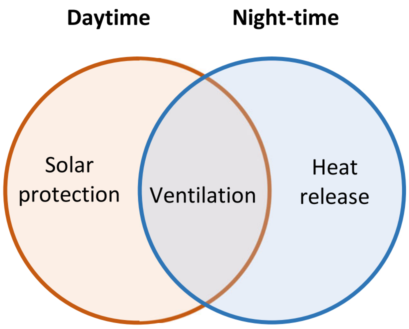


Figure 2: Effective daytime and night-time heat mitigation strategies in urban open spaces in hot arid climate cities.

Providing shade in urban open spaces is essential since urban heat is a common issue in hot arid climates, especially during afternoon hours in summer because of high air temperatures and intense solar radiation.

In addition, other common climate challenges such as drought and flash floods should be incorporated in the design guidelines. Excessive stormwater should be retained to mitigate flooding and can then also be used for irrigation, especially during drought periods. Incorporating such stormwater management strategies help making better design guidelines and eventually prevents an inefficient step-wise rebuilding of streetscapes to deal with separate climate challenges.

To combat urban heat, shading strategies should be wisely chosen and placed based on understanding different shading patterns in different common urban forms. A shading simulation was conducted with Sketch-Up (Fig.3) for the 1st of July 2023 (a typical summer day) and latitude of 24.00°N, where many hot arid climate regions in the northern hemisphere can be found.

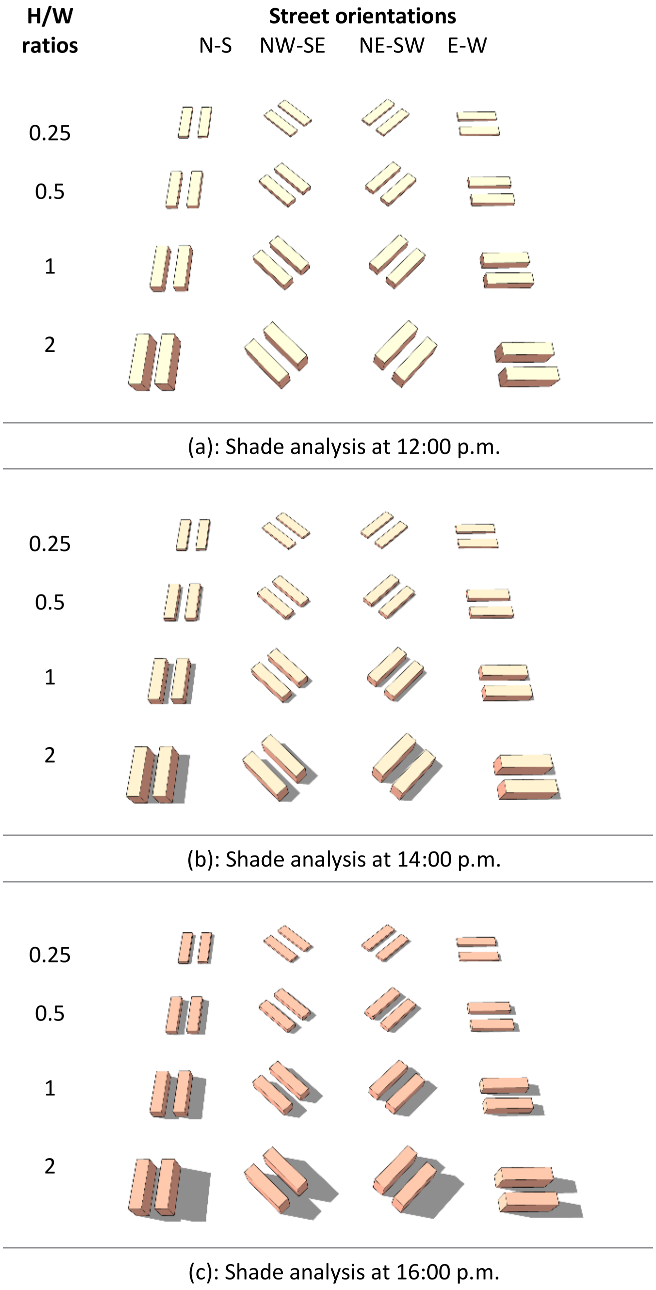


Figure 3: Shading simulation of different H/W ratios of street canyons and street orientations in noon and afternoon hours (between 12:00 p.m. and 16:00 p.m.) on a typical summer day.

Fig.3a shows that there is insufficient shade at 12:00 p.m. in all street canyons with different H/W ratios and street orientations. Thus, providing shade by placing trees or shading devices can ameliorate thermal discomfort, and more likely support people's outdoor physical and social activities.

Fig.3b shows that different street canyons with different H/W ratios or orientations can offer shade at 14:00 p.m. However, low H/W ratio of 0.25 and E-W oriented streets provide very limited shade in different scenarios.

Fig.3c illustrates that buildings can offer more shade at 16:00 p.m., especially, if the H/W ratio is high (H/W=2) in N-S, NE-SW, and NW-SE oriented streets. However, E-W does not provide shade in H/W ratios ≤1.

Overall, shading strategies should be provided in urban open spaces with high and low H/W ratios and different street orientations. Shade analyses can help to wisely place shading interventions, especially for the hot afternoon hours in summer.

The following climate-responsive design guidelines aimed at mitigating increased daytime and night-time temperatures (heat mitigation strategies) by providing adequate shade (vertical shade from buildings and horizontal shade from trees and shading devices) and allowing spaces for ventilation and night-time heat release.

These design guidelines are:

- While shading from buildings can be adequate during most of the daytime hours in hot arid climates, at 12:00 p.m. (midday) this shade is limited in all H/W ratios and street orientations, (see Fig.3a). Therefore, shading from buildings should be complemented with that of horizontal shading devices or trees (Fig. 4).

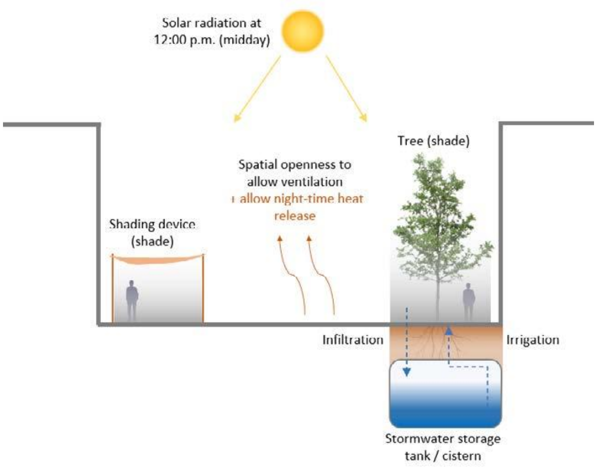
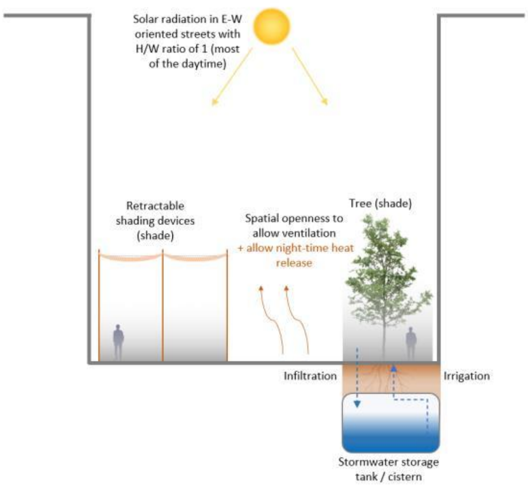
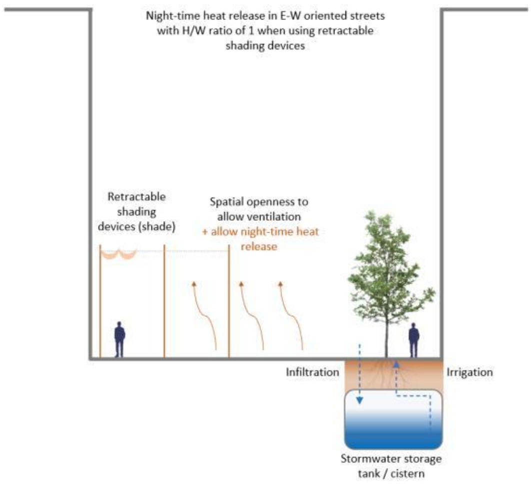


Figure 4: Shading devices and trees can provide shade when urban open spaces are used at 12:00 p.m. This street canyon has a low H/W ratio of 0.5, and these shading strategies can be applied in different street orientations (N-S, NW-SE, NE-SW, and E-W).

- Retractable shade canopies can be used in E-W, NE-SW, and NW-SE street orientations to accelerate the heat release at night, especially if it is difficult to plant trees (e.g., due to underground infrastructure, street functions or limited street width) (Fig. 5).
- Shade should be implemented in in streets with a low H/W ratio and E-W oriented streets with trees or shading devices as they can provide shade and decrease the amount of solar radiation, which can be similar to the effects of high H/W values (≥ 1). However, care should be taken to not obstruct neither air flow nor night-time heat release (Fig. 6).
- Afternoon sun tends to be stronger in hot arid climates. Thus, the placement of climate-responsive design interventions should take into account the possibility of providing cooling effects for afternoon activities in urban open spaces.



(a): Retractable shading devices provide shade at daytime.



(b): Retractable shading can accelerate heat release.

Figure 5: Retractable shading devices can used to provide shade and accelerate night-time heat release, especially in narrow streets with low SVF values.

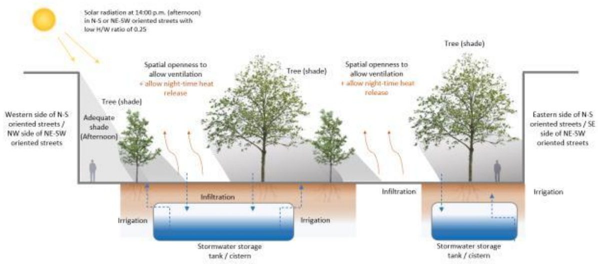


Figure 6: The placement of trees in wide streets with low H/W ratio of 0.25 in N-S and NE-SW oriented streets to provide shade at 14:00 p.m. (afternoon).

- The placement of trees on the western side of N-S oriented streets may not be necessary as buildings can provide adequate shade during harshest hours of the day, from afternoon until the sunset (Fig.7).
- If the shade of trees is needed and the width of a street is limited, place tree pits in the parking space next to the sidewalk. These tree pits can be used to manage stormwater runoff and provide a sustainable source of water for irrigation as drought is a common issue in hot arid climates (Fig.8). However, it is essential to consider the size of the tree pit as small tree pits may lack the needed volume of soil for growing trees to reach the mature size.

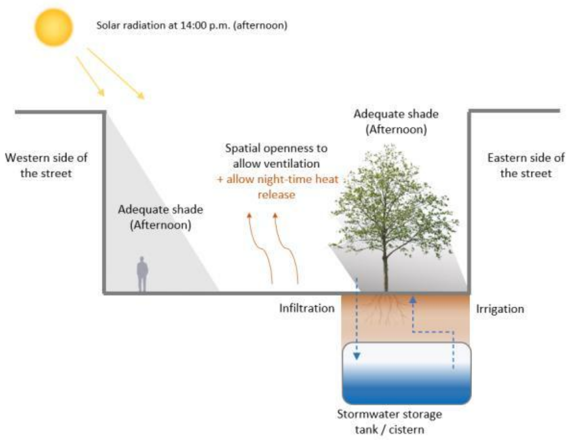


Figure 7: The placement of trees on the western side of north-south oriented streets may not be necessary as buildings can provide adequate shade from afternoon until the sunset.

- In wide streets (around 25 meters or more), there are two possible designs for trees to provide adequate shade and proper ventilation: 1) place a single row of large trees on each side of the wide street, 2) place double rows of small trees on each side of the street (Fig.9). Also, it is possible to combine them by placing a single row of large trees on one side, and place double rows of small trees on the other side.

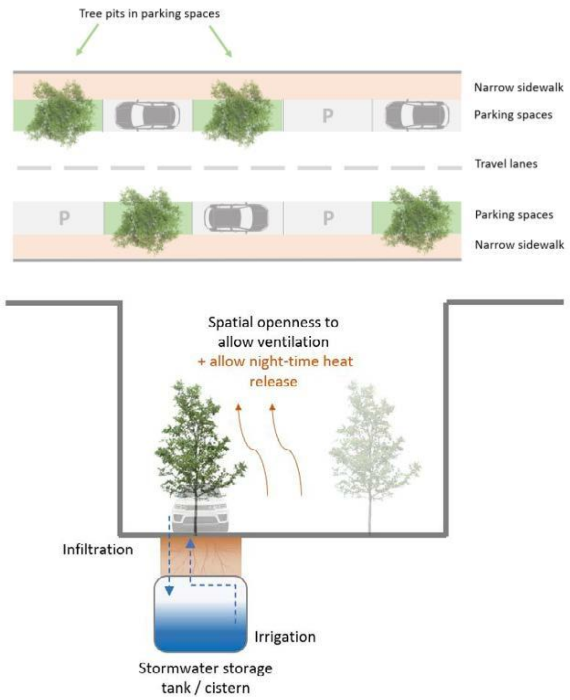
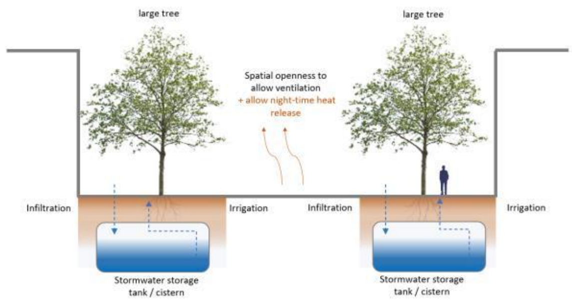
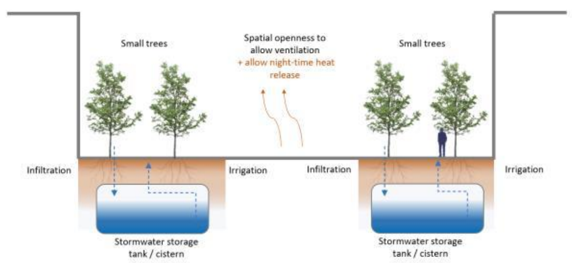


Figure 8: The placement of tree pits in parking spaces to provide adequate shade for pedestrians in narrow E-W oriented streets.



(a): Single row of large trees



(b): Double rows of small trees

Figure 9: The placement of small and large trees in wide streets to provide adequate shade and proper ventilation.

- Planting heat and drought-tolerant tree species is recommended in hot arid climates as these tree species can withstand the harsh climatic conditions.

These design guidelines are promising in improving outdoor thermal comfort conditions in urban open spaces in hot arid climates. Some of these design guidelines can also address other common climate issues in hot arid climates (e.g., drought, flashing flooding) and provide water resources for irrigation which is essential for trees.

4. CONCLUSION

The information accessed through the literature review was scarce and indicated the need to extend the existing design guidelines. The previous studies on climate-responsive design in hot arid climates that were found mainly focused on urban form and less on other solutions.

The RfD conducted was a first attempt to create design guidelines from the studies accessed with the literature review, also considering stormwater issues. Presenting these guidelines spatially was considered useful to communicate these guidelines to spatial designers.

The cooling effects delivered by the implementation of the design guidelines presented in this study should be tested through numerical simulations using models such as ENVI-met. In particular, further research is needed to extend the integrated design solutions and test the cooling effects of placing trees and shading devices in different H/W ratios and street orientations. This testing will allow having a better grip on the outdoor thermal comfort requirements in hot arid climates.

It is essential to consider climate-responsive design guidelines at the early design stage of any urban open space project in hot arid climates as these design guidelines provide guidance for spatial designers to achieve outdoor thermal comfort and minimize thermal discomfort, especially in summer.

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