Redesigning of building envelope: tree bark as a biomimicry concept

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Abstract

For years, nature has provided an abundance of blessings for mankind. Besides its obvious and direct role, the task that has been most evident is its ability of adaptation. Biomimicry has provided an inspirational foundation for many innovations. In this paper, tree bark has been chosen as the main focus of observation in order to scrutinize and analyse complex structures that contribute to the tree envelope's efficiency. Many concepts have been extracted based on its anatomy and modifications. They have then been applied to a residential villa located in Dubai, United Arab Emirates (UAE) in order to create a low energy consumption building. The aim of this paper is to evaluate the extracted techniques thoroughly and discover the function and mechanisms of its parts. New strategies will be developed to apply to the selected case study. Shading, thermal insulation and cavity walls were among the used techniques. Eventually, the building's performance with the new strategies will be evaluated using computer simulation software and compared to the original case. The paper revealed very promising results for enhancing the building envelope's performance with the possibility of energy consumption reduction reaching around 34%.
Keywords: biomimicry, energy efficiency, IES software, building envelope, tree bar, energy simulation.

1 Introduction

'Sustainable Design' may provide the key that balances the earth's resources and consumers. Over the years, many challenges that humans are dealing with nowadays have already been resolved in nature by insects, animals and plants through adapting to their surroundings. All organisms within their ecosystems can provide us with ideas to generate not only sustainable, LEED buildings, but also

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restorative developments that offer the same rank of soil fertility, oxygen and water filtration as the original environment [1]. These natural lessons are called ‘Genius of Place’ and ‘Biome’. This has led to a new way of creative thinking called ‘Biomimicry’. In buildings, what separates the exterior from the interior is called the ‘building envelope’ [2]. Over time, understanding the importance of the building envelope has increased; however, a vast acceleration and focus on financial income, regardless of the consumption of energy, has resulted in neglecting that envelope; thereby widening the gap between nature and the built environment. Sozer [3] pointed out that buildings are considered top rank in negatively affecting the environment’s natural resources. Paying close attention to this envelope is the key to lowering energy consumption and saving natural resources. The goal of this study is to improve the efficiency of the building envelope in the selected case study by applying different strategies. These strategies have been concluded from studying tree bark as a natural concept which plays a similar role to a ‘tree envelope’.

2 Methodology

Steps have been set by the Biomimicry Institute [1] as guidelines for a new era of innovation. This research follows these steps by choosing a natural concept (tree bark), studying it thoroughly and discovering the function as well as the mechanisms of its parts that help it adapt to the environment. By evaluating the results and extracting these lessons, new strategies will be developed and applied to the selected case study. The building’s performance with the new strategies is evaluated using the simulation software program IES VE (Integrated Energy Simulation) [4] and compared to the outcomes of the original case. Climate Consultant version 5.4 software with data from the US Department of Energy is used to extract results from the Psychometric chart [5].

3 Case study

3.1 Location

The villa is located in the northeast of Dubai, one of the seven emirates of the United Arab Emirates, see figure 1. The building is a duplex (semi-detached) from the east direction. The front facade faces south and lacks shading. The western elevation has two large windows that also lack shading. Construction regulations followed the minimal commercial regulations for Dubai which are considered far from being ‘green’ regulations.

3.2 Climate

Dubai’s climate is a hot and arid desert environment. Summers are very hot with high humidity. Winters are short with mild temperatures. It is very important in such climate to minimize heat gain as much as possible by providing proper orientation and shading elements, as well as limiting the windows on the west elevation.

Figure 1: Site location.

4 Bio-inspired strategies

The tree bark as shown in figure 2 has been used as a natural inspiration for this research where many of its properties have been highlighted such as: self-shading, low heat loss and maximum reflection [6].

Figure 2: Natural concept.

4.1 Protection

The bark consists of two main layers, the outer and the inner bark. The outer bark consists of dead cells and forms the first line of protection between the inner bark's vital structure and the surrounding environment. The inner bark or phloem actively contributes to the tree's life processes [6].

4.1.1 Extracted strategy

A multi-layer skin building envelope will provide extra protection from thermal gain. One method of improving thermal insulation for the walls of the building is by applying multi-layered exterior walls with a high R-value. Brown and Dekay, [7] pointed out that double skin materials have a double task: one is reflecting solar heat and the other is to prevent that heat from penetrating into interior areas. Moreover, Ching [12], stated that cavity walls will enhance wall performance in two ways: by increasing the wall's thermal insulation value and by working as a barrier againt water leakage.

4.2 Shading

During the growing process of the tree, xylem tissues push the circumference outwards which causes the outer layer of the bark to tear and die. Some barks form peeling crusts, while others react by forming deep cracks. These outcomes contribute to the tree's adaptation towards the sun by providing 'shade' [6].

4.2.1 Extracted strategy

Self-shading and shading devices protect windows from direct solar gain while maintaining daylight.

Shading strategies are very important in order to block direct sunlight without compromising daylight. This is essential during hot summers in temperate regions [3]. From a shading point of view, a building with merely windows on the north and south elevation is considered best [8]. However, windows with different orientations demand different shading treatments. For instance, east and west elevations benefit from vertical fins to protect windows from the low sun, while southern elevations profit best from horizontal overhanging shading.

4.3 Reflection

The tree bark has optimal reflecting characteristics which is active due to the tannins [9].

4.3.1 Extracted strategy

Exterior wall materials should be capable of reflecting solar heat to minimize the transfer of heat to the interior. Brown and Dekay [7] explained that in old buildings with poor insulation, if light colors are applied to the exterior walls, this will cut energy consumption by 7–12%. That percentage will increase to 13–22% in new well-insulated houses. Since highly reflective materials cause glares, it is advisable to use surfaces that have the ability to diffuse sunlight.

For all new buildings, at least seventy five percent of the area of externally painted walls must have a minimum light reflective value of forty-five percent.

4.4 Insulation

Within the bark, the waxy thick layer of cork plays a very crucial role in preventing water lose in plants [6].

4.4.1 Extracted strategy

Applying thermal insulation materials reduces the amount of energy consumption for both cooling or heating loads. Proper installation for the insulation will define the maximum thermal insulation or R-value [10].

4.5 Material conductivity

One of the functions of the inner bark is to transport sugars for the plant, this occurs via conducting tissues that have been produced by the phloem. This process works under precise procedures in order to assure completion of the task in the correct manner [6].

4.5.1 Extracted strategy

Installing high performance glazed units will provide the required balance between the need for daylight and heat gain. Not only does the glazing control solar radiation, it also controls the amount of daylight and its qualities, which are among the important aspects related to glazing. Good glazing properties will provide thermal comfort as well as a pleasant visual appearance.

3M [9] pointed out on their website that 20–40% of heat can be transferred through the windows. By increasing the glazing layers, the percentage of lost or gained heat decreases dramatically. Glazing should be chosen based on intended needs taking into consideration any related issues.

Glazing frames and spacers on smart windows should reduce thermal bridging. Furthermore, low conductance frames with low values are also issues to consider [2].

5 Strategy implementation

Figure 3 shows how the extracted strategies have been applied on the building. Since the main objective in any hot region is to protect the building from solar gain, horizontal shading devices are installed on the southern windows. Frames that consists of horizontal overhangs and vertical fins that are slanted 45° away from the south are applied to the east and west elevations. This kind of shading is considered the best application for such orientations [11]. Cavity walls replace the existing ones and polystyrene insulation is applied to all external walls. Double-glazed windows replace the existing single ones and eventually, a reflective material is added as a final coat for the exterior walls. A cool roof is also provided. The efficient case follow Dubai's Green Regulation.

All the implemented strategies are applied by using IES energy simulation software (see figure 4) and their efficiency levels are individually evaluated as well. The building profile is set as a fixed parameter in all simulations. The second parameter has all the variables that need to be assessed.

6 Data and analysis

By applying the shading strategy, it is noted in figure 5 how the overhang shading elements on the southern windows provide a good protection from the solar gain. This strategy contributes positively in reducing the energy consumption for cooling purposes.

The solar exposure of the southern elevation has been minimized as a result of applying the shading elements in the efficient case. See figure 6.

The result of shading elements in mitigating the sun effects is noticeable; moreover, figure 7 shows the percentage of decreasing the solar exposure of part of this elevation (kid's room).

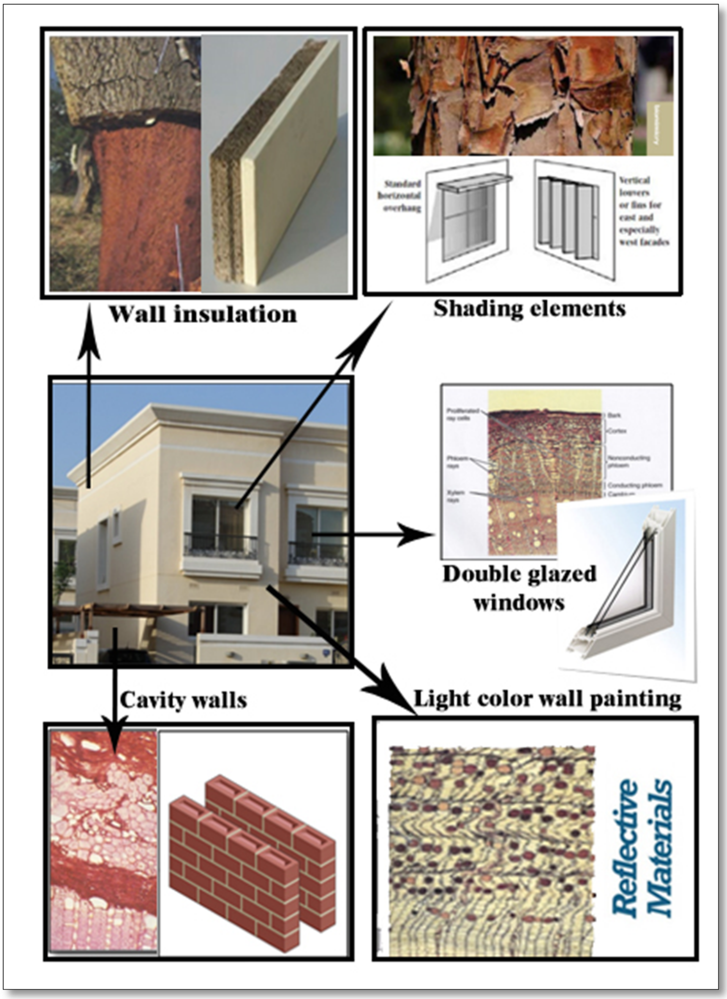

Figure 3: The strategies and their applications.

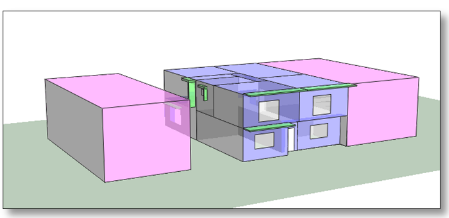

Figure 4: Building computer model.

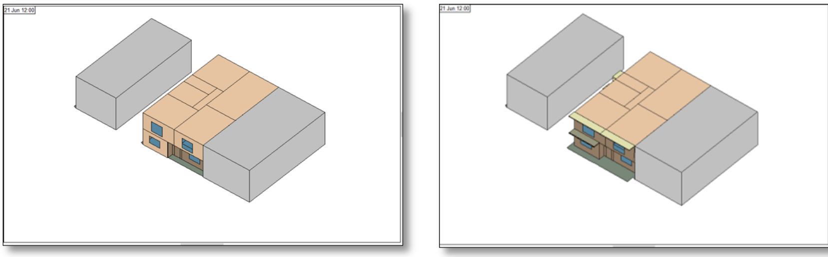

Figure 5: The base case without shading elements (left) and with shading elements in the efficient case (right).

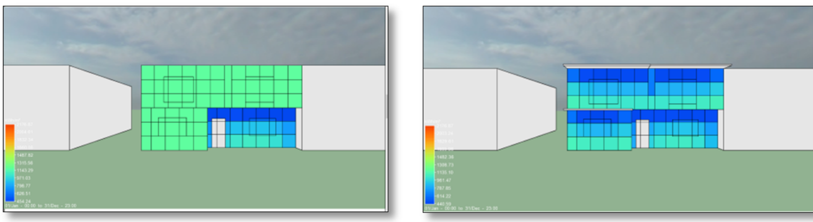

Figure 6: Solar exposure for the base case (left) and the efficient case (right).

Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan								100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0							
Feb							100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0						
Mar							100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0						
Apr							0.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0						
May						0.0	0.0	0.0	0.0	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0						
Jun						0.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0					
Jul						0.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0					
Aug						0.0	0.0	0.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0						
Sep							100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	0.0						
Oct							100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0							
Nov							100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0							
Dec								100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0							

Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan								79.1	64.6	58.8	55.6	54.2	55.2	58.5	63.2	70.1	83.9							
Feb							97.4	64.8	54.0	48.3	45.2	43.8	45.1	49.2	54.8	61.9	72.0	94.5						
Mar							62.6	31.9	26.3	23.8	22.8	22.6	25.8	32.4	40.2	46.1	57.7	86.8						
Apr							0.0	0.3	0.0	0.0	0.0	0.0	5.8	15.0	25.0	33.1	0.0	0.0						
May						0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.9	14.5	24.0	0.0	0.0	0.0						
Jun						0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.2	0.0	0.0	0.0	0.0	0.0	0.0					
Jul						0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.6	12.7	0.0	0.0	0.0	0.0	0.0					
Aug						0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.1	13.9	23.7	31.7	0.0	0.0						
Sep							39.9	1.2	0.0	0.0	0.4	1.5	8.3	17.4	27.1	36.3	60.4	0.0						
Oct							67.4	51.2	43.7	39.9	38.0	37.5	41.4	46.9	53.9	61.3	76.8							
Nov							89.3	68.7	59.3	54.8	52.4	51.6	54.1	58.2	63.8	72.3	88.8							
Dec								78.5	65.8	60.2	57.4	56.4	57.9	61.3	66.2	75.3	89.6							

Figure 7: Sun cast for the kids' room southern elevation.

Figure 8 shows the slight reduction of peak cooling load on August 5th as a result of applying the shading strategy. The time between 13:00 and 16:00 captured the maximum benefit of this strategy.

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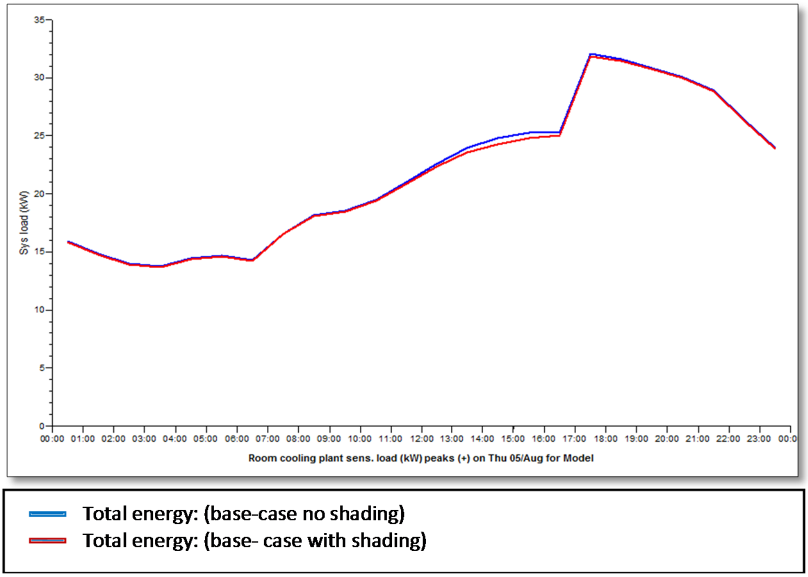

Figure 8: Peak cooling load (KW) for the base case with and without shading.

Table 1 shows the monthly cooling plant load with all the different strategies. It should be noted that applying insulation material and double glazed windows are the most efficient strategies among all those applied at 15.5% and 15% respectively. The optimal case – which includes all the strategies and follows Dubai's Green Regulations – showed a remarkable reduction in cooling plant load that reached up to 34%.

Table 1: Monthly cooling plant load MWh.

Date	Base case	With shading	Shading and reflective materials	Shading and insulation	Shading and double glazing	Shading and cavity walls	Optimal case
Jan 01–31	0.4763	0.3556	0.3493	0.5974	0.0948	0.4706	0.198
Feb 01–28	1.325	1.0679	1.0221	1.2184	0.6416	1.1652	0.695
Mar 01–31	2.9324	2.6409	2.5719	2.5174	2.1052	2.6235	1.919
Apr 01–30	6.1018	5.9096	5.6957	5.1105	5.0079	5.5538	4.125
May 01–31	9.9528	9.8641	9.369	8.1465	8.468	9.0237	6.622
Jun 01–30	11.5867	11.5252	10.9379	9.4139	9.9238	10.4737	7.665
Jul 01–31	13.3835	13.3027	12.5858	10.7792	11.5189	12.0376	8.832
Aug 01–31	13.7169	13.552	12.8281	10.9728	11.8329	12.249	9.092
Sep 01–30	11.5451	11.1779	10.6066	9.1074	9.8013	10.1415	7.599
Oct 01–31	8.4787	8.0883	7.7448	6.8149	6.9723	7.4656	5.589
Nov 01–30	4.6039	4.3629	4.2634	4.0153	3.522	4.2201	3.095
Dec 01–31	1.4091	1.2595	1.2696	1.5199	0.7611	1.4008	0.914
Total	85.5121	83.1067	79.244	70.2137	70.6499	76.8253	56.35

Figure 9 shows the annual cooling plant with each implemented strategy. It is noted that the best recorded results for those strategies are during the summer. Moreover, the figure shows that the optimal case which combines all the applied strategies provides the best performance regarding total energy reduction.

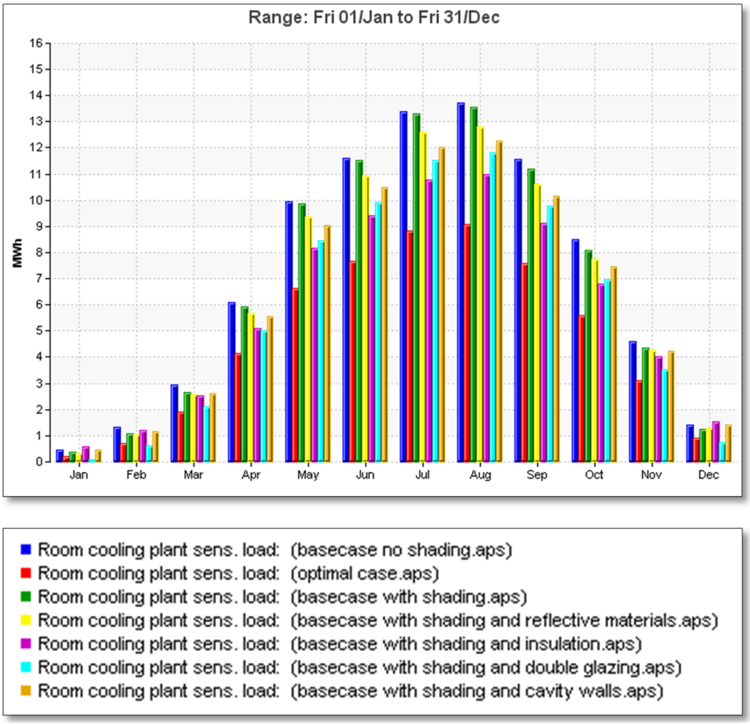

Figure 9: Annual cool plant load (MWh) with all strategies.

Figure 10 shows the peak dry bulb temperature and the cooling load in both the base case and the optimal case. It should be noted that an increment in the dry bulb temperature causes a rise in the cooling load; however, by around 18:00 the cooling load shows another increment despite the decrease in the dry bulb temperature. This occurs because of the usage of artificial lighting which contributes to some internal heat.

7 Conclusion

The main goal was to analyze the role of bark as an envelope to the tree trunk. Furthermore, extracting those mechanisms would improve human building envelopes. This study reveals many remarkable mechanisms underneath. Different strategies have been derived from examining these mechanisms which focus mainly on improving and enhancing the efficiency of the envelope of a residential

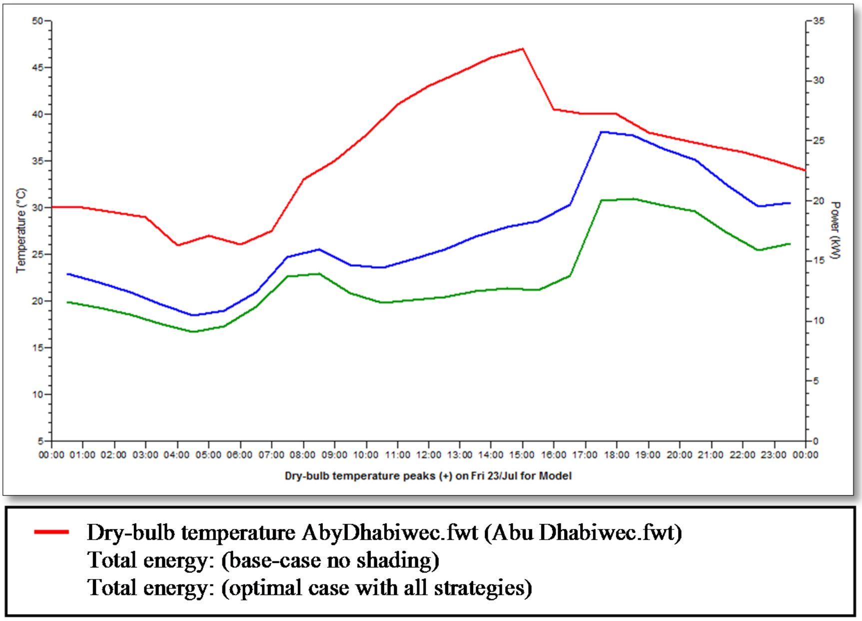

Figure 10: Cooling load for the base case and the optimal case with the relation to the peak dry bulb temperature.

villa in Dubai. Moreover, they take into consideration the climate characteristics and natural elements for that particular region. Comparative analysis and simulation has been conducted regarding skin materials, shading, ventilation, daylight and insulation. These strategies were applied by using local materials to reinforce the meaning of sustainability. Among all the extracted and applied strategies, double glazed windows and wall insulation show the best results with regard to saving energy. However, applying all of the strategies as an optimal solution result in increasing the efficiency of the building envelope alongside a remarkable reduction in energy consumption. In conclusion, every creature in the world has a specific role in completing the entire image of existence. Learning to live with nature in harmony, rather than conflict, is the first step towards a new way of living. Nature provides a source of unlimited inspiration for an improved life. Changing our perception could be the key to a healthier environment and a greener world.

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